LONDON G. BELL AND SONS, LTD.
York House, Portugal St., W.C. 2.
NEW YORK: HARCOURT BRACE & CO.
BOMBAY: A. H WHEELER & CO.

LABORATORIES

THEIR PLANNING AND FITTINGS

BY

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AUTHOR OF "THE CHEMISTRY OF BUILDING MATERIALS," AND
JOINT AUTHOR OF "NOTES FOR ARCHITECTURAL DRAUGHTSMEN"

WITH A HISTORICAL INTRODUCTION BY

SIR ARTHUR E. SHIPLEY, G.B.E., Sc.D., LL.D., F.R.S.

LONDON

G. BELL AND SONS, LTD.

1921

TO

LATIMER AND HIS MOTHER

THIS BOOK IS DEDICATED

PREFACE.

SHOULD this little book prove of service the credit for its genesis must be given to the enterprise of the publishers. In justification for its appearance all that need be said is that search has not revealed any work now in print published in this country which endeavours to deal with laboratories in a manner calculated to bring a building committee, a professorial staff and their architect on common ground for what is essentially a joint undertaking. In so large a field limitations have had to be decided upon, and these pages are confined to the consideration of buildings and fittings for what may be termed educational science as contrasted with technical and workshop requirements. After some general remarks on initiating schemes, an attempt has been made to deal with the specific requirements of chemistry, physics, biology and geology. This is followed by descriptions and illustrations of some recent designs of various magnitudes.

The author is indebted to a great many contributors who have either given up time to show him their buildings, or furnished drawings or information for the illustrations; he is also under much obligation to the few published works available for reference, and it is hoped that due acknowledgment has been made individually in the text for this valuable help. In addition his special thanks are due to Sir Arthur Shipley, ex-Vice-Chancellor of Cambridge University—one of the most progressive of our educationalists—for the valuable historical introduction which he has contributed to the book; to his friend Mr. Arthur Hutchinson for advice and help in connection with the examples at Cambridge, and to his assistant, Mr. J. R. Smith, who has made by far the larger number of the actual drawings for reproduction.

A. E. M.

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LONDON, W.C.

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ERRATA.

P. 70, last line, *for* "now" *read* "not".

P. 213, line 14 from foot, *for* "second floor" *read* "first floor".

HISTORICAL INTRODUCTION

BY

SIR ARTHUR E. SHIPLEY, G.B.E., Sc.D., LL.D., F.R.S.

MR. ALAN E. MUNBY has asked me to write an Introduction to his work on Laboratories. The work is a very serious contribution to a very difficult subject, demanding highly technical and expert knowledge. This the author has, and he has produced a book which will have a permanent effect on all institutions where laboratories are being built.

I fear my Introduction is somewhat diffuse, and all I can plead is that I have done my best.

" Practical work " was carried on long before Laboratories were thought of, and the first case of practical work that I can trace in history is connected with my own College. Christ's College was originally founded in 1448 by King Henry VI as God's House, and placed on or near the site of the western end of King's College Chapel. Later King Henry moved his foundation beyond the Barnwell Gate, outside the city boundaries, where in 1505 it was refounded as Christ's College by Margaret Beaufort, Countess of Richmond and Derby, and mother of King Henry VII. God's House was founded as a school for grammarians, and its members took the degree of Master of Grammar. Before he could incept for his degree the candidate for the degree of Master of Grammar had to perform a certain act of practical work. This act is thus set forth in the ordinances of the time :—

"Then shall the Bedell purvay for every Master in Gramer a shrewde boy, whom the Master in Gramer shall bete openlye in the Scholys, and the Master in Gramer shall give the boye a grote for hys labour, and another grote to hym that provydith the rode and the palmer (i.e. ferrule). And thus endythe the Acte in that Facultiye."

Thus before he could proceed to his degree in Grammar the applicant had to prove his capacity for this most important function of his future life.

The next example of practical work that I recollect is that followed at Dotheboys Hall by Mr. Wackford Squeers :—

"This is the first class in English spelling and philosophy, Nickleby," said Squeers, beckoning Nicholas to stand beside him. "Now, then, where's the first boy?"

"Please, sir, he's cleaning the back parlour window," said the temporary head of the philosophical class.

"So he is, to be sure," rejoined Squeers. "We go upon the practical mode of teaching, Nickleby; the regular education system. C-l-e-a-n, clean, verb active, to make bright, to scour. W-i-n, win, d-e-r, der, winder, a casement. When the boy knows this out of the book, he goes and does it It's just the same principle as the use of globes. Where's the second boy?"

"Please, sir, he's weeding the garden," replied a small voice.

"To be sure," said Squeers, by no means disconcerted. "So he is. B-o-t, bot, t-i-n, tin, bottin, n-e-y, ney, Bottiney, noun substantive, a knowledge of plants. When he has learned that bottiney means a knowledge of plants, he goes and knows 'em. That's our system, Nickleby; what do you think of it?"

"It's a very useful one, at any rate," answered Nicholas.

"I believe you," rejoined Squeers. . . . "Third boy, what's a horse?"

"A beast, sir," replied the boy.

"So it is," said Squeers. "Ain't it, Nickleby?"

"I believe there is no doubt of that, sir," answered Nicholas.

"Of course there isn't," said Squeers. "A horse is a quadruped, and quadruped's Latin for beast, as everybody that's gone through the grammar knows, or else where's the use of having grammars at all?"

"Where indeed!" said Nicholas abstractedly.

"As you're perfect in that," resumed Squeers, turning to the boy, "go and look after *my* horse, and rub him down well, or I'll rub you down."

In neither of the cases, that of the incepting Masters of Grammar and that of Mr. Wackford Squeers, was much apparatus or any specially designed building required.

Roger Bacon (1214-1292), the Franciscan monk of Oxford, was the first to teach "the only true method by which the advancement of scientific learning can be effected, e.g. the methods of experimental science—

SINE EXPERIENTIA NIHIL SUFFICIENTER SCIRI POTEST".

Roger Bacon must have had a laboratory, for he clearly distinguished between speculative alchemy and practical alchemy, the latter of which he regarded as more important than the other sciences because "it is productive of more advantages". Several spots in or about the city of Oxford have been pointed out as his "studies or laboratories". Roger Bacon was, of course, persecuted by the Church, and spent many a long year in confinement. Much that he did has been lost to us and some of the claims of his admirers have not been upheld; but nothing can detract from the fact that he stood at that time far ahead of all other leaders of thought.

As time went on the astronomer gradually broke away from astrology, and the chemist and physicist ceased to be necromancers and occultists. But for a long time many of them, even some of the most learned, were half impostors. Browning surrounds us with the atmosphere of the laboratories of the middle ages in one of his songs in "Paracelsus," half genius and half quack:—

Heap cassia, sandal-buds and stripes
  Of labdanum, and aloe-balls,
Smeared with dull nard an Indian wipes
  From out her hair: such balsam falls
Down sea-side mountain pedestals,
  From tree-tops where tired winds are fain,
  Spent with the vast and howling main,
  To treasure half their island gain.

And strew faint sweetness from some old
  Egyptian's fine worm-eaten shroud
Which breaks to dust when once unrolled;
  Or shredded perfume, like a cloud
From closet long to quiet vowed,
  With mothed and dropping arras hung,
  Mouldering her lute and books among,
  As when a queen, long dead, was young.

And in his "Laboratory" we can almost see what was going on and realize that the necromancer was not far from the poisoner:—

Now that I, tying thy glass mask tightly,
May gaze thro' these faint smokes curling whitely,
As thou pliest thy trade in this devil's smithy—
Which is the poison to poison her, prithee?

Grind away, moisten and mash up thy paste,
Pound at thy powder—I am not in haste!
Better sit thus, and observe thy strange things,
Than go where men wait me and dance at the King's.

That in the mortar—you call it a gum?
Ah, the brave tree whence such gold oozings come!
And yonder soft phial, the exquisite blue,
Sure to taste sweetly—is that poison too?

Perhaps the Astronomers with their Observatories and the Anatomists with their Dissecting-rooms were the first habitually to use special buildings set apart for the pursuit of their subjects. Later the Chemists and the Physicists followed suit. By the fifteenth century physics and chemistry were also demanding special facilities for research. Leonardo da Vinci (1452-1519) probably had a delightful jumble of a studio and a laboratory, for he was both a great artist and a great man of science. During the sixteenth century the great Belgian anatomist Andreas Vesalius (1514-1564) had broken loose from the bond of the written word which had strangled research for a thousand years, and had looked at the structure of the human body for himself; he taught only what he could himself see and what he could make his pupils see. Without knowing it he was a disciple of the Great Oxford forerunner, Roger Bacon. Under him Anatomy was the first of the natural sciences to break loose from the scholastic domination which had hitherto ever placed authority above experiment. "To look with the eyes is to confound the wisdom of ages," as Walt Whitman reminds us.

During the time of the Tudors a Chymist's, or as they called it, an Apothecary's shop was largely a Laboratory; but not so much for teaching, beyond what an apprentice or two may pick up, as for the compounding of chemicals and drugs.

The Doctors then, as some do still, made up their own medicines and dispensed them.

A typical example of the physician's laboratory was that of Jonathan Goddard, an M.D. of Cambridge, who was doctor of Cromwell's army and was made by Cromwell, Warden of Merton College:—

"When he was ejected his Wardenship at Mert. Coll. (which was in 1660) he lived mostly in that of Gresham, where (being an admiral Chymist) he had a Laboratory to prepare all Medicines that he used on his patients, besides what he operated for his own satisfaction."

Pepys records how at Whitehall Charles II had his "little elaboratory, under his closet, a pretty place," and was working there but a day or two before his death, his illness disinclining him for his wonted exercise. The King took a curious interest in anatomy; on May 11, 1663, Pierce, the surgeon, tells Pepys "that the other day Dr. Clerke and he did dissect two bodies, a man and a woman before the King, with which the King was highly pleased". Pepys also records February 17, 1662-63, on the authority of Edward Pickering, another story of a dissection in the royal closet by the King's own hands. As we have seen from the case of Charles II, in the Stewart times laboratories were found in the houses of the great, but they were laboratories in the main for research and not for teaching. Probably they were connected with the museums of "rarities" which many great noblemen then possessed.

One of the earliest laboratories for teaching in our country that I have been able to trace was that of "Peter Sthael of Strasbourg (a Lutheran, a great hater of women, and a very useful man)". He was brought to Oxford by the celebrated Robert Boyle, so often referred to as the father of chemistry and brother of the Earl of Cork. Boyle's laboratory is shown in a charming picture in Dr. Gunther's fascinating "Early Science in Oxford". Sthael's classes grew from three in 1659 to six in the following year, and to over a dozen in his third year. Amongst his pupils were John Wallis, Professor of Geometry, Christopher Wren and John Locke, who was, it is sad to read—

"A man of turbulent spirit, clamorous, and never contented. The club wrote and took notes from the mouth of their master, who sat at the upper end of a table; but the said J. Lock scorned to do it; so that while every man besides of the club were writing, he would be prating and troublesome."

Now who would ever have thought that of the author of the "Essay Concerning Humane Understanding"?

In 1664 Sthael seems to have retired to London, and there he died, though before his death he had returned to Oxford for a short period. It is worth noting that the fee for the lectures and practical work was then much as it still is, at any rate in Cambridge, £3 for the course.

The first laboratory that I can trace in Cambridge was founded by Francis Vigani (1650?-1712) some years later. Vigani was a Doctor of Verona; about 1683 he came to reside in Cambridge, and soon became an acknowledged teacher with a high reputation. In 1703 he was invested with "the title of Professor of Chemistry"—as one "who had taught

Chemistry with reputation in Cambridge for twenty years previously". He was our first Professor of Chemistry, unpaid.

At that time Masters were indeed Masters, and the celebrated Dr. Bentley, Master of Trinity College, was domineering over, bullying, fighting, and at times but not at all times cowing his Fellows. The Master was desirous of annexing the College bowling green and adding it to the garden of the Master's Lodge—in fact, this high-handed attempt was one of the charges made against him to the Bishop of Ely in 1710. The scheme was strongly opposed by the Fellows, and eventually Bentley had to abandon his design. At the east end of the bowling green was part of the old King's Hall, and amongst its rooms was a chamber that Bentley called the "Lumber-Hole," and in this chamber or chambers a laboratory was fitted up for Vigani who had recently been appointed Professor of Chemistry. The following Order, the terms of which are said to have been selected with the express purpose of preventing any future encroachments by the Master, shows that the laboratory occupied the ground floor of the old buildings of King's Hall, on the east side of the bowling green.

"Febr. 11th 1706-7. Orderd . . . y^{t} the low Chamber under y^{e} Old Hostle adjoyning to y^{e} Gate be made and fitted into a Laboratory for y^{e} use of Chymistry, and Physics and Philosophical Experiments; and y^{t} it never be converted to any other use."

A contemporary pamphlet gives some account of the feeling that was aroused by the attempt of Dr. Bentley which ended so happily in the establishment of the first Cambridge chemical laboratory. The pamphlet describes the efforts of the Master to capture the bowling green, and it concludes with some rather disparaging remarks as to the courses that were given there :—

"For if the Design had not miscarry'd, Then had this old Lumber-Hole been an Elegant Green-House for Dr. Bentley: But since they wou'd not do That, He resolved He'd be even with 'em for their Stubbornness; and if it cost them a Hundred Pounds the Lumber-Hole should be made, and Constituted, and for ever after call'd, an Elegant, Chymical Laboratory. I am none of those who glory in running down Chymical Observations and Experiments; but yet with regard to this so famous Laboratory of Ours, I have talk'd with those that have gone the Courses, and they All seem to be of Opinion, That as those matters are manag'd, the Learned World is not like to reap any mighty Profit or Advantage from anything that is There taught."

The establishment of Vigani's laboratory is often put down to Bentley's great desire to improve the teaching in the College and University. But I am afraid the above recitals put a somewhat other and certainly less favourable view on the proceedings. In spite of the order "y^t it never be converted to any other use," the "Lumber-Hole" has been converted to other uses and is now part of the Bursar's Offices. But one could write a book on the history of laboratories, and I fear my readers would weary if I continue on this one topic. Let us take a great leap and come down to my own experiences as a student forty years ago.

When I began to study Botany in 1879 at St. Bartholomew's Hospital the only attempt at practical work was to hand flowers round in the lecture room, which we sometimes dissected, but I am afraid more frequently threw at the lecturer. In the following year when I came up to Cambridge, apart from the Medical School there were recently constructed laboratories for the teaching of Zoology and Physiology; but excepting the Herbarium or "Hortus siccus" there was no laboratory for teaching Botany. That came very little later under the management of Mr. S. H. Vines, who has but just retired from the Sherardian Professorship at Oxford. The Mineralogical Laboratory, if it existed at all, was a small appendix to the museum of minerals. The Cavendish Laboratory, however, was then, as now, doing work which has made it the Mecca of all physicists throughout the world. The Chemical Laboratory was there also, but ill-housed and inconveniently arranged. The Engineering Laboratory hardly existed, though there was a room or two in which wooden models constructed by Prof. Willis were housed. All that is changed, and Cambridge has now a finer set of laboratories for teaching work as well as for research than any other University in the Empire. If I have any criticism to make of them, it is that there is a want of spaciousness in their staircases and passages. Charles Lamb used to say that the turn-stile leading into Lincoln's Inn Fields was made so narrow because such very fat people used to get through. Perhaps the same reason accounts for the straitened dimensions of some of our passages and staircases. Then again there is a plentiful lack of lifts, and this wastes a great amount of time and energy.

Huxley (1825-1895) gave an enormous stimulus to practical work when n the 'seventies he started his classes at the Royal College of Mines, South Kensington. It was he who systematized the teaching of what is called

elementary Biology. He recognised the fundamental unity of plant and animal life, and he illustrated his lectures by the study of types first of all of the simpler forms of unicellular animals and plants, and gradually passing through the more lowly multi-cellular organisms he at the end arrived at the mammal and the flowering-plant. He was aided by a brilliant staff of demonstrators, amongst whom I may mention Sir William Thistleton Dyer, late Director of the Royal Gardens, Kew; Professor S. H. Vines and Professor Newell Martin, who carried Huxley's ideas beyond the Atlantic, and first started in the United States the modern system of laboratory instruction in elementary Biology to large classes. From Huxley's laboratory the light spread to France and Germany and other parts of the Continent, though for a long time Britain, as she so often has done in scientific matters, led the way.

As a system grows old it tends to ossify, and to some extent this is true of the teaching of elementary Biology. The schedule for the First M.B. has hardly changed since I first began teaching in Cambridge University in 1884. Too much attention was then given to details and too little to broad generalizations. The course of preliminary biological science at Edinburgh gave a much wider view of animate nature than was given, at any rate at one time, by the study of a limited and unvarying list of type forms. A student who passed through the ordinary M.B. elementary Biology could emerge at the end of it believing that a whale was a fish and having but little or no knowledge of adaptation, symbiosis, natural selection, marine life and other fascinating aspects of plants and animals. It is true that the Edinburgh student did less practical dissecting, but he used the museum more.

The sort of teaching I have tried to indicate has now spread from the University and University Colleges to the schools, and most schools that can possibly afford it have now fairly well-equipped laboratories for the boys and girls to work in. This has been a very heavy strain on the resources of many poorly endowed institutions, and very great self-sacrifice has been needed to provide the necessary buildings.

I have two or three suggestions to make to those who are responsible for constructing laboratories and lecture rooms. Perhaps the most important refers to the relative positions of the magic lantern and the screen on which the pictures are shown. In nearly every lecture room I have been in, the lecturer faces the lantern and turns his back toward the screen. Hence, when he wishes to point out features in the picture he has to twist round, and then

his back is turned upon his audience. Now, if the lantern were placed in the far corner, to the left of the lecturer, and the screen in the near corner on his right, he could more or less face the pictures and his audience at the same time. The only way to overcome the present difficulty is to arrange a looking glass in front of the lecturer to reflect the pictures. This plan was suggested to me by Dr. A. C. Haddon, and it works very well, but it gives the audience an erroneous idea of the lecturer's memory as he recites the long list of slides seen by him only in the glass, without turning to look at the screen.

The second great difficulty in building laboratories is to get the maximum of light, and on this I have a word to say. If the "splay" of a window be not at right angles to the wall, but slope outward from the edge of the window to the inner surface of the wall, and if it be painted white, a very great increase in the illumination of the room is brought about, with but a small loss in the strength of the outside wall.

Thirdly, for classes which require microscopes, the front seats next to the window are at a distinct advantage over the second or third rows further back in the room. Now, if V-shaped tables be constructed, whose bases are as wide as the width of the windows, five or seven students at each table can get a very adequate light of almost equal intensity; and the broad base of the V takes up only about as much space as two laboratory places set at a table parallel with the outer wall and immediately fronting each window.

Another point—a small one, it is true—is that the lecturer should be able to lower and turn up the light of the room from his lecture table. In the room in which I am at present lecturing the attendant has to run up and down some steps to do this, a process which is disconcerting to the taught as well as to the teacher.

We have seen that the great monk, Roger Bacon, said that the advancement of science can only be effected by methods of experiment. His teaching fell on deaf ears. Three hundred and fifty years later his namesake, Francis Bacon (1561-1626), in Elizabethan times re-affirmed this great principle, and from Francis Bacon's spacious time till now it has never been forgotten.

The gap between the mediæval science which still obtained in Queen Elizabeth's time and the science of the Stewarts was bridged in a way by Francis

Bacon. He was a reformer of the scientific method. He was no innovator in the inductive method; others had preceded him, but he, from his great position, clearly pointed out that the writers and leaders of his time observed and recorded facts in favour of ideas other than those hitherto sanctioned by authority.

Bacon left a heritage to English science. His writings and his thoughts are not always clear, but he firmly held, and, with the authority which his personal eminence gave him, firmly proclaimed, that the careful and systematic investigation of natural phenomena and their accurate record would give to man a power in this world, which, in his time, was hardly to be conceived. What he believed, what he preached, he did not practise. "I only sound the clarion, but I enter not into battle;" and yet this was not wholly true, for, on a wintry March day, 1626, in the neighbourhood of Barnet, he caught the chill which ended his life while stuffing a fowl with snow, to see if cold would delay putrefaction. Harvey, who was researching whilst Bacon was writing, said of him: "He writes philosophy like a Lord Chancellor". This perhaps is true, but his writings show him a man, weak and pitiful in some respects, yet with an abiding hope, a sustained object in life, one who wrought through evil days and in adverse conditions "for the glory of God and the relief of man's estate".

Though Bacon did not make any one single advance in natural knowledge—though his precepts, as Whewell reminds us, "are now practically useless"—yet he used his great talents, his high position, to enforce upon the world a new method of wrenching from Nature her secrets, and, with tireless patience and untiring passion, impressed upon his contemporaries the conviction that there was "a new unexplored Kingdom of Knowledge within the reach and grasp of man, if he will be humble enough, and patient enough, and truthful enough to occupy it".

In conclusion, may I say, that in my opinion this book will be a real help to those engaged in investigating the secrets of Nature—to all those who are in Francis Bacon's sonorous words working "for the glory of God and the relief of man's estate".

A. E. SHIPLEY.

Christ's College Lodge,
March 10, 1921.

[*From an Engraving dated* 1822.

An Early XIXth Century Design for a General Laboratory.

AUTHOR'S INTRODUCTION.

THE history of natural science teaching in England forms a very marked illustration of our national conservatism, and even to this day the number of our public men who personally know anything of this field of study, and are thus in a position to appreciate its value, is so small, that science has still to take its due place in a liberal education in this country. For while it is probable that no one would deny the value of such study for those destined for technical pursuits, there are many who entirely fail to appreciate the value of science as part of a general curriculum. When one reflects that only a quarter of a century separated the design shown in the frontispiece from the birth of the Science and Art Department, it seems strange that three times this interval has not carried us further to-day. The exhibition of 1851 is usually regarded as the starting point of our science training, but even 1889, the date of the Technical Instruction Act, found science in most of our schools a thing apart, taught to a few specialists, a condition which probably Clifton College can claim to have first endeavoured to dispel. Since those days the powers of Public Authorities in the matter of devoting money to science teaching have grown so vastly that the facilities for such study in State-aided schools threaten to compete seriously with those in many independent schools possessing great traditions. In like manner, as the result of grants and private munificence, university education in science has much developed in recent years. These advances, however, must be regarded not as contrasted with our previous position, but in the light of what other countries have been doing, and with the object lessons of the late war before us it is clear that we have reached another great epoch in educational history, which, unless we are to fall behind the other nations of the world, must produce real practical results in the development of science teaching, not merely as a means to a commercial end, but for its own intrinsic educational value.

CHAPTER I.

SCOPE AND INCEPTION OF BUILDING SCHEMES.

SCHEMES for supplying the material requirements of education in Natural Science differ so widely in extent and character that any generalizations within the compass of a little book are not very easy. As stated in the preface the scope of this volume is limited to what may be termed pure science for general educational purposes, the demands of which may range from the fitting up of an ordinary class-room for occasional practical work to a complete building of the university type designed for one or more specific subjects. While not professing to deal with the special needs of what is known as "technical education" it will be found that the requirements for the early stages of such work, which consists largely of pure science centred round some trade, are practically covered, while a good deal of senior technical work is more a matter of special plant and apparatus than of buildings and equipment of a different order.

Factors which Control Schemes.—There are many factors which must be adequately considered before any ideas can materialize and instructions be given profitably to those who will be responsible for carrying out a building scheme. Not only will the number and ages of the students and the funds at disposal affect the problem, but also the extent of the teaching which may involve duplication of some of the accommodation; the location of the students who may be resident in an attached institution or come from some distance; and the provision of the requisite sources of energy for heating and lighting and of power for experimental purposes, and whether any plant thus involved is to have an educational value for the students, in addition to its material service. In the smallest schemes suitable for general elementary work perhaps a single large room may have to serve for all purposes, both demonstrative and practical, and the room will have to answer also for all preparative work and the storage of materials. In a small secondary school it is usual to find a laboratory for practical work, a lecture room,

which is sometimes an ordinary class-room fitted with a suitable table for demonstrations, and in addition a store and preparation room or both, while in the larger and more modern secondary schools where two or three branches of natural science are taught, a special lecture room and two or three laboratories with their preparation rooms and store rooms special to the respective subjects, also a balance room, optical room, and perhaps a special laboratory and private room, are commonly found. In schemes of university type each branch of science is naturally made a complete unit and is often in a separate building entirely distinct and self-contained. Sometimes, indeed, this unit system is applied to branches of a particular science. Thus, one building or floor, complete with all its main and subsidiary rooms and staff, may be required for Inorganic and another for Organic Chemistry. This unit system has undoubted advantages where it is justified. It not only admits of entirely independent use of a department or all departments together, each under its own scheme of time table, but it defines the spheres and responsibilities of the teaching staff in a manner calculated to give an incentive to progress. It must not be forgotten, however, that not only the initial building outlay of such a system but the running cost in staff and upkeep is a serious factor. A compromise between the unit and the fused systems may often be satisfactorily attained when neither seems applicable, by adopting separate main rooms such as lecture theatres and laboratories, while certain rooms not in such general use, such as balance rooms, dark rooms, and those not directly used by the students, are so planned as to be available in common by two or more departments.

Subjects to be Taught.—For the benefit of those not conversant with educational programmes a word may be said upon the divisions of natural science. Opinions differ as to the relative merits of the branches of science as educative training, but Physics, Chemistry, and, much less generally, Biology, are usually regarded as the most suitable fields for a beginning, often preceded by a course of general science which, while inculcating some of the fundamental principles and drawing on all the above subjects, often extends into the domain of physiography and mensuration. Physics, essentially the science of measurement, is well designed not only to teach habits of accuracy and reasoning but to awaken an interest in all natural phenomena dealing with the various forces of nature upon inert matter, and its applications to all kinds of mechanical and electrical appliances are so direct and

numerous, that it can hardly fail to arouse an interest. Physics is for convenience usually subdivided into Mechanics, Heat, Electricity, Magnetism, Light and Sound, the first three being perhaps most amenable to advantageous elementary treatment for large laboratory classes. Chemistry, which investigates the composition of materials and the relation and properties of their component parts, is essential for a proper understanding of the natural changes in the world around us, while its interest in connection with the artificial production of useful substances has recently received great stimulus in this country. It is usually divided into Inorganic and Organic Chemistry, the latter, concerned with the products of animal or vegetable origin and those of mineral origin containing carbon, is not taught until a good grounding in inorganic work—that is, general chemistry—has been obtained. Biology which is concerned with the life processes and structure of plants and animals offers not only a field of direct interest in natural surroundings but provides great educational openings in the matter of classification and minute observation. This subject is subdivided into Botany and Zoology, each of which may be again sub-divided into Physiology, Morphology, and Classificatory branches. Another subject which, though it seldom finds a recognized place in a school curriculum, plays an important rôle in many university courses, is Geology, and perhaps no country in the world offers such a diverse field for the applications of this study as our own.

It is with the material requirements in the shape of buildings and fittings of the above subjects that this book will endeavour to deal, but while such divisions of science are necessary for the purpose of describing the requirements entailed, it must be remembered that a great change is taking place in educational methods and that natural science is likely in the future to become, at least in its elementary stages, more and more diffused into other school subjects so that eventually every class-room may require some special fittings, while the rôle of the laboratory as a thing apart may gradually disappear. Such evolution is well exemplified in the teaching of geography. The Continuation School, again, will presently make its effect felt on secondary education. In such schools interest will centre round some particular trade or trades, and general education be acquired by working back from such interests to the principles which underlie them. Thus it may be that secondary schools will find a means of arousing an enthusiasm at times needed in some of their pupils by following in the higher forms a

modified scheme of a similar character. Such considerations must affect laboratory equipment and should not be lost sight of in decisions as to the elaboration of any scheme embarked upon.

Size of Classes.—If the building is entirely independent, the provision to be arranged can be based solely on the anticipated size of classes, a matter, nevertheless, often as much bound up with the personality of the staff as with the needs of the district. Where attendance is compulsory, however, as in a school, it generally happens that the numbers are regulated by other subjects. The tendency is for the size of school classes to decrease, and in secondary schools, twenty-five may perhaps be taken as the average number ; a junior form may contain thirty, but the higher forms will often consist of less than twenty. Now experience has shown that one teacher cannot adequately take a class of more than about fifteen in practical work in a laboratory, although this number may be considerably exceeded for lecture work. This is not a question of discipline but of the requirements of individual supervision. Large laboratory classes involve a very stereotyped course of work which fails to call out initiative, and unless the teacher's hours are short or he has much laboratory assistance, submit him to an undue amount of labour which must react detrimentally on his pupils. A school laboratory, therefore, should either accommodate the whole of the largest class with the possibility of two members of the staff taking such classes together, or should be arranged for the largest class which cannot be split up into two sections, the large classes, appreciably over fifteen boys, being divided and each half using the laboratory at separate times. The former arrangement is preferable as giving more space and thus licence for altered conditions. If the school has a complete science side the size of the classes can, of course, be controlled with much greater independence.

Laboratory work in higher institutions seems likely to become more individual in character, and it is not improbable that the large rooms capable of accommodating a hundred or more students will eventually give way to smaller rooms containing fewer fixed fittings and having some resemblance to research laboratories.

Necessity for Co-operation.—For the successful carrying out of any scheme, proper collaboration between the organizers, the architect and the staff who are to "run" the building is most essential, and so many misunderstandings and disappointments arise through lack of appreciation of

this fact that something may be legitimately said on the subject. It is often stated, and with some justice, that the ideal committee is a committee of one, and a building scheme, if not in the hands of one individual, should certainly be relegated to a quite small special committee, which will formulate the requirements in outline and call in their architect at a very early stage. If the teaching staff already exists its views should be voiced before any instructions are issued to the architect, and if not, it is highly desirable to make some appointment in advance of any building, so that the scheme of work can be arranged and the actual requirements fore-shadowed as much as possible. It constantly happens that buildings are erected before the teachers are appointed, and unless some member of the building committee is both an educationalist possessing an intimate knowledge of the requirements of the subjects to be provided for, and is, in addition, prepared to devote a great amount of time to the problems calling for solution, the architect is often imperfectly informed as to what is necessary. A building committee should be prepared to work very hard until it knows what it wants and has enabled its architect to embody these ideas in a good set of sketch plans, after which it should define the extent to which it desires to call upon his services, and having done so and accepted the necessary tenders from the trades, under the architect's advice, it should leave him thoroughly in touch with the head of the staff of each department, when, save for the control of unforeseen changes necessitated in the scheme, it may feel that its duties are very largely over.

Obtaining Tenders.—The material necessities for teaching science may be grouped under three heads: the buildings, the fittings, and the apparatus, and the allocation of responsibility under these headings should be properly defined and may vary in different cases with the magnitude of the scheme, the views of the building committee, and the personal attention and knowledge which the prospective working staff can contribute to the details of the problem. The design of the building, including its internal surface finishings, and decorations, and the supplies for heating, lighting, ventilation, and power, are the province of the architect, who will obtain competitive tenders based on his drawings and specifications, and unless the outlay is trifling (under £1000) will instruct a surveyor to "take out quantities," that is to dissect the prospective building and measure it up, placing the bricks, stone, timber, and so on, in groups in the form of a bill to which the builder

tendering can attach his prices. In works of any magnitude, since builders obtain only about one contract in every twenty for which they compete, this labour of dissection is too great to admit of tendering against other firms were it thrown on the builder himself, hence the necessity for "quantities," the cost of which is usually included in the building tender. This cost is, of course, much more than repaid by the decreased cost of the building obtained as the result of competition.

Responsibility for the Fittings.—Fittings include all fixtures and furnishing requirements in the building necessary for its intended uses, apart from actual experimental apparatus. Students' benches, lecture tables, preparation benches, sinks, desks and seats, dark blinds, brick built benches, furnaces and the like, cupboards and shelves for storage, and the working terminations of supplies such as gas and water taps, electric fittings and fans, come within this category. These are generally dealt with in one of two ways: they are either placed in the hands of the architect, or some firm or firms who sell such goods are called in and given a large measure of freedom as to what is supplied. To deal with the latter case first, the responsibility of detailing requirements and the necessary negotiations are here thrown upon the building committee or the science staff, and though the special experience of these firms is undoubtedly valuable, there are in this country not a great number who possess facilities for conducting such work as part of their own businesses, which are usually more concerned with the manufacture and sale of actual laboratory instruments and apparatus. If, with a very proper wish to obtain the financial benefit which usually accrues from competitive tendering, it is decided to ask several firms to give a price for the fittings, it will be found that the necessary knowledge for the production of a detailed specification, on which alone fair tendering can be based, is probably not forthcoming without professional advice, in the absence of which those firms who only undertake first class work in a conscientious manner are likely to be heavily penalized by less scrupulous competitors anxious to obtain the contract. Further, there is a natural tendency on the part of the firm selected to make use of designs which it already possesses, which do not necessarily best meet the special requirements of the case, and unless difficulties are to arise, the architect's drawings, and in most cases his approval of many details, will be necessary, as the fittings must conform to his prearranged construction. If the former method is adopted, the whole of the

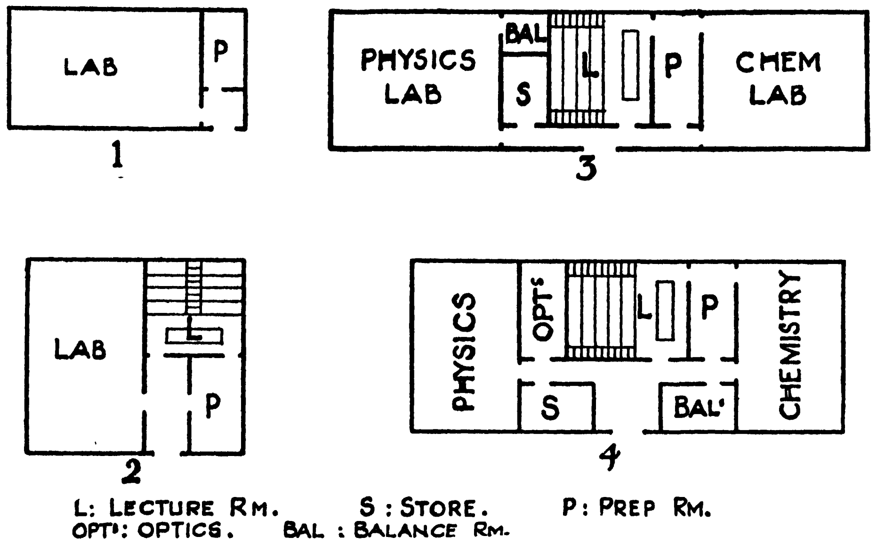
fittings being placed under the architect's care, specialist firms can still, if desired, tender and will do so on adequate particulars and drawings which will ensure fair competition. The committee and staff will have an opportunity of discussing and settling in detail the various requirements previous to any financial commitment as to the work, and this will be carried out under the architect's supervision and in harmony with the other details of the design. Further, it generally happens that a large proportion of these fittings consist of joinery and the like, which can be quite well constructed in the shops of a general contractor given adequate drawings, and may thus be included in the main building tender, if such details can be decided upon early enough in the scheme, or he may be given an opportunity of tendering against specialist firms. It may of course happen that the architect does not wish to undertake the equipment details, his practice not having carried his experience in this direction. On this subject the writer was recently interested and entertained by the views of an enthusiastic professor who stated that he would much rather have an architect who knew nothing of science fittings than one who thought he knew something. Where, however, special guidance by the science staff is not forthcoming, recourse may always be had to a consultant who would act in a purely professional capacity, like a consulting engineer, and it may sometimes be convenient or desirable that such an appointment should be made under the architect as the final authority alone responsible to the building committee, the consultant's fees being paid through the medium of the architect.[1]

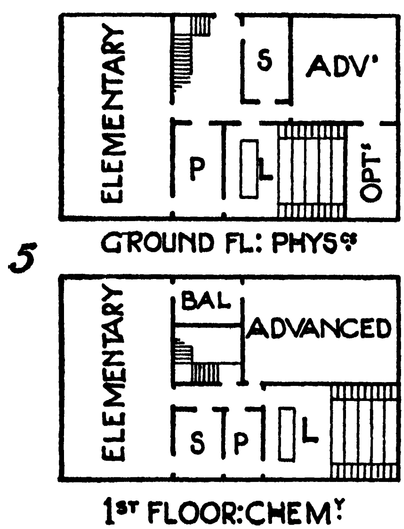
Finally the apparatus is almost invariably selected by the professorial staff, and, subject to adequate provision for its appropriate housing in the fittings, can be regarded as an isolated matter, which again emphasizes the desirability of making suitable staff appointments previous to the fruition of any scheme.

Planning and Arrangement.—While the general principles of planning are essentially part of an architect's training which cannot be dealt with here, a few notes as to the arrangement and relation of the various rooms and departments may prove of value. One of the first things to be recognized by a layman is that a successful plan can seldom if ever be utilized

[1] The scale of professional fees of architects, which are never included in building estimates, can be ascertained on application to the Secretary of the Royal Inst. of British Architects, 9 Conduit Street, London, W.

without very considerable modification in another situation. Questions of slope of the ground, aspect, surroundings, and location of entrances and





Figs. 1-5.—Diagram Plan of Simple Buildings.

exits all have to be regarded in the design of a building, and no two sites present similar conditions for all these factors. Hence even for similar conditions for work and accommodation, utilization of a previous plan is never completely possible. The relations and sizes of different rooms are, however, matters which admit of some generalizations, and a few simple types of small buildings are given in the form of line diagrams showing the kind of way in which ideas may be expressed on paper for the architect to translate into practical form. **Fig. 1** shows a combined laboratory and lecture room with a little store or preparation room attached, and forms the simplest possible example. **Fig. 2** illustrates a laboratory, small lecture room and preparation room. **Fig. 3** shows two laboratories with a lecture room between them, off which

is a preparation room, while off one of the laboratories is a small balance and store room. **Fig. 4** gives the same general arrangement, with the subsidiary rooms enlarged, and a preparation and balance room adjoining the chemical laboratory, while off the physical laboratory is an optical room and a store near the entrance. **Fig. 5** shows a two story building with a small complete physics department on the ground floor and chemical department on the first floor.

In a building of any magnitude means of access to the different departments and facilities for rapid exit have a very considerable bearing on its administration. Where a complete administrative series of rooms is provided, it may be desirable to have a separate access for the staff, but those for the students should be under ready supervision and not more numerous than really necessary, as every external door involves a certain amount of attendance. Means of exit should always admit of two alternative ways of escape in case of fire or panic, and if external doors cannot open out, a matter sometimes difficult to arrange happily, they should stand open during working hours and an internal door or pair of doors adjoining such exit should be provided either to open out or swing. Much saving in corridors may often be effected by centralizing main entrances and staircases, but as far as corridors are necessary these should not be too narrow as they are almost invariably used by large numbers together. Though rooms should not be used as passage ways a good deal of communication for the staff and attendants between different rooms will be found necessary, as it is desirable to reduce as far as possible the need for carrying apparatus through passages. Symmetry in the arrangement of both the rooms and the fittings in them will assist order, and the more simple and straightforward the plan of the building and its contents the better will it be in the working. It will not usually be found necessary to urge an architect to produce a symmetrical plan, because in formal planning—no science building should ape the inconsequent charm of certain types of domestic architecture—symmetry is of great assistance in the design of suitable elevations, and the building should have at least one axis, if possible.

Aspect is important but must be considered in relation to surroundings. For example, a laboratory, not a lecture room, should be placed on a noisy side of the building, and there may be rooms seldom used except in the evenings which might most suitably occupy rear ill-lighted positions in

planning on restricted areas. Aspect is also related to the subject taught; for example, rooms for microscopic work require a steady north or north-east light, for physiography one window facing due south, and for horticultural botany an open south aspect. A great deal of light is required for all science work, observations in every subject being at times of a very minute nature, and as wall space is always required abundantly for fittings top lighting is often desirable, or in storied buildings, rooms sufficiently lofty to give both ample wall and window area. Top lighting, of course, necessitates further provision for warming and may be trying in very hot weather, but as most students are absent from the end of July to well into September the latter objection carries less weight than would appear due to it at first sight. The provision for artificial light must also be on a much more generous scale than for an ordinary room, the actual sources of light being, however, screened from the eyes and directed on to the fittings upon which they are required.

Floors for Subjects.—As to the floors to which, in storied buildings, different subjects should be allocated, heavy machines, furnaces benefiting by good draught, rooms wanting an equable temperature, stock and like rooms not frequented by students usually find a place in a basement. Physical laboratories, on account of vibration, generally enjoy a ground floor, though in the vast majority of cases this is by no means essential. Chemical departments, though this adds to outlay on drainage, are most often found on upper floors, while biological subjects, where concentrated and quiet work is more in vogue and where light and sun are of especial importance, are most suitably disposed on a top story where access to a flat roof is often obtainable.

Teaching and Use of Rooms.—Opinion still seems to be divided as to the desirability of combined laboratories and lecture rooms. For advanced work a separate lecture room is invariably provided, but in some schools one room in which the students can both do their laboratory work and sit at desks listening to a more or less formal demonstration as desired, is favoured in place of a separate lecture room and laboratory. The relative merits of these arrangements depend upon the style of the teaching intended. For junior work, with a restricted staff, and when the use of the two separate rooms at one time is not likely to be required, the combined room would seem to be desirable, but in cases where the numbers at a lecture are likely

to be large, a separate room is generally essential, as a very large combined room would not only often involve a loss of its use for other students but also entail difficulties in the due preparation of apparatus for subsequent work and possibly have acoustic disadvantages.

Opinions again differ as to whether a lecture room should be only sufficient for a single class, or accommodate an audience such as might be expected at a popular lecture. A decision on such a point must rest largely upon the special conditions of the building and its prospective uses, and it may often be found an economy to fit up in some other hall, not part of the science block, a properly equipped lecture table to enable a scientific demonstration to be given when occasionally necessary, and thus save space for devotion to the more important needs of the actual laboratories. An unnecessarily large lecture room not only wastes space but throws a strain on the voice of the lecturer, and, moreover, involves more upkeep in heating, lighting, and cleaning.

One Room for Several Subjects.—For very elementary work or where funds will not admit of adequate provision, a single laboratory sometimes has to serve for different subjects at different times, and although this cannot be regarded as desirable, it is quite possible to do a great deal of useful elementary teaching in such circumstances. Among the designs illustrated in a later chapter will be found one or two examples of such schemes. An ordinary school class-room or a drawing office, where the desks' tops are horizontal, can well serve for elementary physical, biological, and physiographical work of certain kinds, and as the training of hand and eye becomes more general in education, it is quite likely that the ordinary class-room fittings may have to undergo a change to adapt them to such work quite apart from specific science periods. At best, however, a good deal of hardship in the matter of clearing up, and some consequent loss of time will result, if anything requiring more than the most simple apparatus is to be employed.

If chemistry and physics are to alternate in the same laboratory, the nature of the fittings should give way to physics as regards free bench area and access, sinks being confined to the ends of the benches or even to the sides of the room and ample provision should exist in the matter of well-made cases for physical apparatus as a protection from the inevitable corrosion from chemical vapours. All fixed reagent shelves on the benches should be

excluded and every provision made for adequate ventilation. If this is done and the chemical experiments are selected with some little regard to the circumstances, physical apparatus of school standard may be made to last a long time.

Use of Old Buildings.—It is not likely that any attempt will be made to utilize old buildings erected for other purposes, for science teaching in any very permanent or extensive scheme, though in exceptional circumstances, where the lighting of a room is, or can be made, adequate and any difficulties as to drainage, ventilation, condition of flooring, and other kindred matters, can be overcome, there is no reason why a good laboratory should not be produced by such means, and an example of such a conversion is illustrated in Chapter VI. It will seldom be found, however, that a series of rooms planned for other uses will fulfil the working requirements of a department, and obviously chemistry is less amenable than other subjects to the limitations of an old building on account of its greater requirements in the matter of drainage, ventilation, and supply services. In a small scheme where new buildings could adjoin old and funds are not available for more adequate provision, advantage might be taken of existing rooms for conversion into lecture rooms, or for some branches of physics, and given suitable light and aspect, biology, store rooms, workshops, and any rooms of an administrative nature might also find a home here. Generally speaking, however, a science building to work well should be designed *de novo* for its specific purposes.

Further remarks upon the relations and sizes of various rooms will be found in the chapters dealing with specific subjects.

Expansion.—In these days of rapid changes and especially at the present time when the very conservative views as to the utility of science are giving way to more enlightened conceptions, changes and expansion in any scheme of provision for science teaching must be looked for. The nature and extent of the fittings and service supplies in laboratories render alterations often somewhat difficult, and though the relative claims of the present generation and posterity should be fairly assessed, bearing in mind that the character of the latter are necessarily problematical, it is well to conceive boldly even if immediate realization can be only partial. Not only does this prevent an unorganized growth of buildings difficult to work in later years but it provides a constant incentive to the staff to attain to higher things. In a

new centre, or where the probable growth of industries suggests an increasing population, provision for expansion is, of course, particularly necessary, but it may also easily happen that in some old-established institution which has possessed almost constant numbers for generations, some cause, such as a change to more liberal views on education by those responsible for the curriculum, may involve a large increase in science teaching. It is in fundamental matters of this kind that a building committee holds great responsibilities, and some view should be arrived at and made known before the architect puts pencil to paper ; indeed, he may often be usefully brought into such deliberations. Future additions may be schemed by wings or further stories. If, for example, physics and chemistry were to absorb the available time of the students and staff, but it was thought that ten years later biology might be made a school subject, the building might be roofed with a flat and suitable walls provided to carry the additional load, when biology could be installed as an added floor with very little duplicated cost and disturbance, should this be found necessary. If internal alterations to the immediately proposed building are probable, many of the partition walls can generally be constructed so as to be capable of removal by the provision of heavier steel work so that the floor and roof loads are thrown wholly or to a greater extent upon the external walls of the building. This of course involves increased initial cost but much less outlay and disturbance than would be caused by the subsequent introduction of steel work to effect such removal after the building was completed.

Construction.—Science buildings should generally be constructed in a solid and substantial manner, to admit of the adequate installation of drainage and ventilation ducts and supply services, reduce fire risks, and minimize vibration. There is, however, no reason why a building wholly on the ground floor should not be of an almost temporary character if desired, and though this course is not to be generally advocated, since the dignity of a building has no little effect upon the mind of the student as to the seriousness and standing of the subjects taught within its walls, it may sometimes happen that immediate accommodation is necessary with very limited funds though ground is readily available. The fittings in such a building may, of course, be either also temporary, or be substantially made with a view to subsequent use in a permanent building. In this connection a word of warning may be given against the purchase of temporary buildings on

another site for transport and re-erection, without adequate advice. These are sometimes available at what appear very tempting prices, but the cost of removal and re-erection is generally considerable. One of the most difficult things to make a layman understand is the cost of altering and re-using old material both in buildings and fittings. The point generally lost sight of is that time is often worth more than the material which is not amenable to the operations of any machinery but involves individual hand labour. It is thus often cheaper to reject perfectly sound work than to subject it to considerable alteration.

The most suitable materials for the construction of the shell of the building and their relative cost depend very largely on local conditions and are matters of general design outside this discussion. Fire-resisting floors, as contrasted with joists and boards, are always desirable, and among these solid concrete floors are to be avoided owing to their great power of transmitting sound. Some form of hollow terra-cotta block floor is very suitable, supported by reinforced concrete beams or steel girders.

Internal Surfaces.—A study of the short accounts of recent designs in Chapter VI will give some information as to the surfaces of floors and internal walls most suitable for various purposes, but a few general remarks may be made here. As regards walls, glazed bricks and tiles, though permanent and washable, add very materially to the cost of a building, and if alteration in the rooms or fittings are at all likely the difficulty of reconciling these changes to the wall surface treatment must be considered. The most advanced medical opinion seems to favour, on hygienic grounds, plastered walls either painted or distempered, such application being periodically renewed, and the absence of mortar joints in such surfaces is undoubtedly an advantage. Certainly in a bacteriological laboratory this opinion should be followed. Around certain fittings, however, where walls are likely to be soiled, a permanent glazed surface is often a necessity. Walls covered to a fair height with plain panelling, the panels being flush with the framing, offer a continuous surface for the ever-growing shelves and other fixtures, which will be much appreciated by those responsible for conducting the work. A better plan is to provide vertical wooden boards about 3 inches wide on the walls at convenient distances apart, preferably finished flush with the wall face, or sockets may be built into the walls to receive bolts, to which such uprights may be fixed afterwards.

As regards paint it must be remembered that the gases of a chemical laboratory very rapidly blacken lead paints; hence zinc is desirable as a base, anyhow for all but the filling coats, in specifying paint work.

As to floor surfaces, those subject to hard wear and much change of temperature, but not to the action of acids, such as heating chambers, furnace rooms and (for economy) basement corridors, are best finished in cement and fine granite chippings, which forms, however, a cold and tiring floor for general work. Asphalt makes an excellent if unattractive surface for floors subject to much wet or acid splashings, and its pliability is sufficient to admit of its adaptation to slight movements or shrinkages which almost invariably produce some cracks in continuous brittle surfaces. In the main rooms, laboratories, lecture and subsidiary working rooms, wood blocks of hardwood, pitch pine, or deal are generally used, and while these make an excellent floor it is open to question whether narrow boards, similarly laid on a solid bed are not better, as having fewer joints and being easier to clean. In some American school laboratories hardwood boards set in asphalt are used, with a slight fall to the centre of each gangway and thence to a common outlet to provide for flooding emergencies. Wood floors may be advantageously treated with one of the antiseptic dust-preventing preparations from time to time, though these preparations generally leave a very dark tint which involves some loss of light by reflection. The use of ordinary linoleum of really good quality may be commended for many situations, and sometimes old wood floors may be "cleaned off," that is, planed level, and covered with this material with excellent results. Unfortunately, linoleum is soon damaged by alkalis such as caustic soda, but in physical and biological laboratories, balance rooms and places not subject to rough wear, it forms a quiet, warm, and very cleanable floor, and as it can be laid on the ordinary cement surface of a floor required for blocks or boards with but little extra cost in preparation, it is economical. Owing to its tendency to "tread out" fixing and trimming should be delayed as much as possible. Tiled floors are cold and noisy; terrazzo (mosaic) floors, though very suitable for corridors, are cold and readily attacked by acids. Finally, there are many patent floors on the market which can be applied in a plastic form to any surface in a layer about an inch thick, which when trowelled smooth gives a continuous surface, the warmth and elasticity of which varies with their composition. These floorings are usually composed of sawdust (often coloured with red iron oxide or

ochre) and cement, usually including magnesium oxychloride, which mixture sets to a hard solid with water. Magnesium oxychloride is always liable to contain free magnesium chloride, a deliquescent body which in the presence of moisture rapidly corrodes metals in contact with it. Although these floorings possess many attractions and have in numerous cases stood excellently it will be seen that discretion in their employment is necessary.

A point often overlooked is the necessity for settling the nature of all floor surfaces before the architect has to specify the floor construction and levels, that is during the preparation of the contract drawings, as owing to the different thicknesses of these surfaces, subsequent changes may involve expense even if no surface has actually been laid, and will sometimes be impossible without small differences in level between adjoining areas.

Supply Services.—Some detailed remarks on the subject of supply services will be found in Chapter V, and it will be sufficient to say here that a modern laboratory requires invariably water, gas, and electricity in addition to adequate ventilation and ordinary warming. For advanced work a steam supply, compressed air, and exhaust service may also be requisite. In these matters chemistry makes the greatest demands; here ample gas and water provision, the latter sometimes at more than one pressure, special ventilation, usually electricity for power and sometimes steam and exhaust systems, are necessary. Physics demands ample gas but only a small water supply; on the other hand, the electrical requirements are often such as to require the assistance of a consultant. Biology only calls for a limited amount of gas and very little water, but some of its branches require electricity and compressed air.

Outlay.—Architects base their first estimates of cost upon the number of cubic feet which a building contains, placing the price per c. ft. at a figure which their experience and knowledge of local conditions indicate is a fair valuation for competitive tendering. Of course this cannot be attempted with any accuracy without plans and sections, but a very rough idea of cost (often a great help prior to seeking professional assistance at all) might be obtained in normal conditions by allowing say 40 sq. ft. per head (to cover wall thicknesses) in laboratories, half this area or rather less in lecture rooms, making some proportional addition for subsidiary rooms decided upon, and adding about 25 per cent.[1] for corridors, staircases, and entrances. Having

[1] This would be a suitable percentage for a good sized building, but much too high for a one-storey simple structure.

thus obtained a rough area for the buildings, this can be multiplied by say 15 ft. as the average height from floor to floor for each proposed storey, plus an addition of 8 or 10 ft. to allow for roofs and foundations. The product of these areas and the total height will give an idea of the number of cubic feet involved. At the present time[1] prices are so uncertain that any statement of cost per cubic foot is quite likely to be misleading as a future guide. It may, however, be said that a substantial building with its drains, heating, and lighting, but excluding all fittings, furniture, cost of site and professional fees, is worth about one-ninth of the cubic feet it contains, in pounds.

It is more difficult to give any approximate cost of the fittings, but some notion of probable outlay may be gathered from the present value of a chemical lecture table and long double bench—the most elaborate needs—shown in **Figs. 12** and **19**, pages 31 and facing 41. These are, with sinks and drainage but without gas or water, about £140 and £100 respectively, as made to architect's drawings by a building contractor.[2]

Succeeding Chapters.—In the following chapters devoted to Chemistry, Physics, Biology, and Geology, an attempt will first be made to review the general scope of the requirements of these subjects and the relations and locations most suitable for different rooms, after which the placing of the fittings, and finally any points of interest in their construction, will be discussed. A short account of the supply services and of drainage and ventilation from points between the fittings and their exits from the building will form the subject of a separate chapter.

[1] Jan., 1921.

[2] The author has to thank the firm of Mr. James Carmichael, Contractor, of Wandsworth, S.W., for kindly giving these figures.

CHAPTER II.

THE REQUIREMENTS OF CHEMISTRY.

NO branch of science makes such heavy demands in the matter of special construction and fittings as chemistry, owing to the varied and extensive nature of the appliances used and the supply services required. Hence it is particularly desirable that a chemical department be designed with its fittings and not erected to be subsequently fitted by some one who has had no responsibility in connection with the design of the building, as this can only result in increased outlay and loss of efficiency. At the same time a general feeling is growing up that the character of fittings could in many cases well be more simple and that such powers of flexibility and expansion as the nature of the problem allows, should be fully utilized. While, therefore, the descriptions here given must necessarily include the more elaborate requirements for advanced work, it should be pointed out that for elementary work such as that requisite in many small schools, where, perhaps, a single laboratory, a lecture room and their adjuncts are alone necessary, it is possible to do a great deal with fittings and services of a comparatively simple and inexpensive nature. This view is strongly advocated by Professor H. E. Armstrong, and it is doubtless better, when funds are limited, to instal simple fittings and devote outlay to apparatus and adequate tuition than to incur such heavy capital expense that current necessities must necessarily suffer. These prefatory remarks seem called for to prevent any layman perusing these pages with a view to elementary teaching, and, having only small funds at disposal, from prematurely deciding that the requirements for his purpose are so extensive that it is useless to proceed farther. On the other hand, it is generally false economy to cut down desirable capital expenditure in any scheme for advanced work, inasmuch as the interest on such additional outlay is usually trivial when compared with current expenses, in salaries and maintenance.

List of Rooms.—The following list of rooms represents fairly com-

pletely the requirements of a chemical department for advanced educational work. In this list the rooms marked (1) are usually the minimum for any separate scheme for chemical teaching, while (1) and (2) would constitute a desirable scheme for a large secondary school. The remaining rooms are seldom found in institutions of less than university standing. As stated in the preface, technical work is not included in this book, but metallurgy, although it may be said to be somewhat of this character, is dealt with because it requires certain fittings of a fixed type and finds a place widely, though not at all essentially, in laboratories not directly devoted to trade interests. In perusing this list it must be understood that in large schemes, rooms must be often duplicated, thus one large and several small lecture rooms, each with its own preparation room and store, may be necessary. Again, each laboratory may have its own balance room, and several combustion and dark rooms may be wanted, while a dozen or more research rooms may be devoted to various purposes. It is impossible to lay down any rule as to the actual needs, which must always vary with local conditions and funds available.

1. General Laboratory.
1. Lecture Theatre.
1. Preparation Room.
1. Store Room.
2. Balance Room.
2. Advanced Laboratory.
2. Combustion Room.
2. Dispensary.
2. Research Laboratory.
2. Dark Room.
Physical Chemistry Laboratory.
Electro-Chemical Laboratory.
Sulphuretted Hydrogen Room.
Closed Tube Room.
Bio-chemical Laboratory.
Library.
Museum.
Constant Temperature Room.
Liquid Air Room.
Metallurgical Furnace Room.
Metallurgical Laboratory.
Acid and Special Store Room.
Workshop, Power Room, etc.
Staff Rooms.

LOCATION AND RELATION OF ROOMS

Some general remarks on planning have been made in Chapter I, and though the relations of rooms can best be appreciated by studying actual designs, with proper allowance for special circumstances which often involve compromise, a few comments are now added with reference to chemical departments generally. The principal floors should naturally be allocated to the large laboratories, lecture rooms and their adjuncts, and to administrative rooms, usually near the principal entrance. The main lecture theatre,

which may run through two stories, and possibly be thus approachable from two floors owing to its raised seating, should be well situated for ready approach from outside the building, and the preparation room which serves it should be behind the lecturer and have an entrance direct into the lecture room in addition to one to the corridor, a further connection being often provided between these two rooms by a fume cupboard, opening on both sides, in the wall between them. In a small scheme it may be desirable that the preparation room also adjoin the main laboratory, as it will probably have to serve as a dispensary and perhaps also as a store for the general requirements of the students.

The sulphuretted hydrogen room, if provided, is required in conjunction with the general elementary laboratory.

Unless a balance room is dispensed with and balances kept in glazed cases in the laboratory, a plan sometimes adopted for elementary work, this room should adjoin the laboratory for which it is required or be accessible therefrom without the necessity for crossing any stream of traffic, since the work of many days may be ruined by a chance collision in reaching this room for weighing. A balance room may often be arranged to serve two laboratories by being placed between them. The advanced laboratory should be arranged in conjunction with the combustion room where lengthy operations dealing with the analysis of organic compounds are carried out; and to the organic laboratory also belongs the closed tube room, if its place is not taken by a bench furnished with the necessary protection in the laboratory itself. An open balcony to this laboratory for certain experiments is often useful.

If a bio-chemical laboratory is provided, it should form a part of the advanced or organic laboratory section, and will probably consist of a small room fitted for general advanced work and a separate room for incubations and culture work, which should be disconnected from the former by a ventilated lobby or other means to keep its atmosphere free from chemical fumes which easily destroy microscopic life.

In the physical chemistry laboratory, a great deal of heating and stirring over long periods generally occurs, hence this work is often carried on in the basement where there is usually less combustible material than elsewhere, but this is not essential. Electro-chemistry requires heavy cables for conveying large currents, hence it is obviously an economy to locate the room for this work as near as possible to the source of power, which may be the supply mains

or actual plant, and almost invariably involves a set of accumulators, usually found in the basement. This laboratory will possess its own switchboard, with probably a very large number of connections to the main switchboard of the building.

Dark rooms must be larger than those usually devoted to photography, and should be near advanced and research laboratories.

A library in a small scheme may be combined with a common room or seldom used reception room, or even with a balance room, but our institutions are apt to be deficient in the supply of works of reference and periodicals, hence the provision of a library should always receive consideration. This room should be within easy reach of all students, who should be encouraged to use it, and space should be reserved for the ready extension of the initial shelving.

A constant temperature room is used chiefly in connection with crystallizations and bio-chemistry, but the great difficulty of overcoming the natural changes in atmospheric temperature relegates it most conveniently to the basement, since the lower down and less exposed to sun and wind, the less need be the elaboration in its construction. As experiments requiring this room only involve very intermittent attendance, proximity to the laboratories is not essential.

A liquid air room, again, partly as containing machinery and partly for the sake of cool and undisturbed conditions, is best placed in the basement, and access to it should be under control, hence only one door to the room is desirable. For metallurgy, the furnace room is almost invariably placed at as low a level as possible in order to secure the maximum chimney draught, which has a considerable influence on the temperature obtainable in the furnaces. The use of coke, ore breakers, and the like, also makes a basement room desirable, but it should be well lighted and supplied with fresh air. The metallurgical laboratory, naturally, most suitably adjoins the furnace room, but if situated on the floor above it should have a stair in connection special to this department.

Stores should provide for the direct delivery of goods with the minimum of handling. Cases are often large and heavy, and an unpacking room, in addition to the actual store room, is very useful. Connection with the preparation rooms or laboratories by a hand lift or other convenient means will save much labour and breakage. Acid and inflammable liquid stores are best arranged with external doors only.

It is now proposed to deal with the requirements of individual rooms in detail, giving a list of the fittings usually wanted, and some comments on their arrangement and spacing, after which, any fittings of special interest will be described, and this plan will be followed in the two succeeding chapters dealing with other subjects. Naturally, certain remarks and descriptions will apply in a great measure to these chapters in common, and to avoid repetition where such similarity occurs, reference will be made in later chapters to such matters which will be dealt with here.

Arrangement of the General Laboratory.—Of all rooms, the main laboratory is the most important, not only as containing the largest number of students, but as the place in which the foundation of their habit of work is laid. The room should be lofty and well lighted, and should be generous in the matter of space, as movement is inevitable. The Board of Education require 30 square feet per head in laboratories in schools coming under their jurisdiction, an area which must be regarded as a minimum and not sufficient for adult students; indeed, unless the room is planned for the fittings, it will often be found difficult to arrange it satisfactorily on this basis. As a matter of interest, the following areas in square feet per head, found by dividing the whole area of the actual laboratory by the number of students it will hold at one time, are given in the case of a few recent buildings: Londonderry Technical School, 32; Newry Technical School, 38½; Berlin Chemical Institute Inorganic Laboratory, 40½; Bristol University Inorganic Laboratory, 50; Harrow School, 52; Cass Institute, London, 55¾; University College, London, Advanced Inorganic Laboratory, 64½; Oxford University General Organic Laboratory, 75 sq. ft. per head.

The usual fittings of a general laboratory are students' working benches, fume cupboards, combustion and general benches, shelving, blow-pipe table, drying ovens, often connected with a still, and a demonstration table on a low platform. Since wall space is very necessary for shelves, cupboards, ovens, and apparatus of a public character, the working benches are never placed round the walls in the manner often adopted in private or research rooms. Usually they are made double so that students can work on both sides, which considerably economizes both space and cost of services, and the best arrangement is that of a series of island (isolated) fittings, placed in parallel rows at right angles to the window walls, which should be the long walls of the room. If the laboratory can be lighted from both sides by

windows, it is very advantageous, as this gives a good cross light unimpeded by fittings down each bench. These benches are often of considerable length: in a room of moderate width they may extend across it, leaving only a gangway along the wall on each side, but if the room be a very large one, a third central gangway is also desirable, parallel to the side gangways. The actual bench lengths adopted will be naturally some multiple of the linear dimension allotted to each student: if 3 ft. 6 ins., which should be regarded as the minimum, be adopted,[1] a bench 10 ft. 6 ins. long will hold three students on each side, but even for elementary work an allowance of 4 ft. each is very desirable, especially with the style of work often undertaken in modern teaching. If the width of the room is such that a bench would much exceed 14 ft. in length, it is better to substitute two benches, with a central gangway between them, which will much improve working facilities though it costs space and possibly increased outlay in drainage and services. It may be of interest to note that all the working benches in the general (both elementary and advanced) rooms in Fischer's laboratory in Berlin are 10 ft. 5 ins. long.

The gangways between the sides of the benches must be wide enough to provide a free passage between the students. In certain operations, such as blow-pipe work, the student has to lean over the bench and thus extend his legs for convenient balance some distance from the bench, hence 6 ft. between the bench tops is not extravagant, and anything less than 5 ft. will involve occasional interruption of work when transit between the two rows of students is necessary. For passage behind a single row of students, as where a bench faces a wall or a little-used fitting for general purposes, a gangway 4 ft. wide will be sufficient. The width of the longitudinal gangways, parallel to the window walls, will depend upon the use to which the wall and window space is put, and whether there are sinks projecting beyond the ends of benches. A very usual practice is to put fume cupboards in the windows, in which circumstances a good deal of standing in these gangways will occur, and 4 ft. clear of all fittings should be given. For a central longitudinal gangway, 3 ft. clear between projecting sinks or other fittings should be quite sufficient.

An arrangement slightly more economical of space is to place the benches

[1] This length is usually accepted as the standard for junior work both in this country and in America.

parallel to the long axis of the room, which has the sole advantage of enabling all the students to more readily turn to face the demonstration table, to obtain any general instructions, if, as is usual, this is placed at one end of the room. A demonstration table, however, is often omitted in large laboratories for adults, and, even in schools, is by no means universal; moreover, if the reagent (bottle) shelves on the benches are above the eye line, no general view of the table from where the students stand will be available. With high side windows or top light no serious objection to this arrangement exists as far as lighting is concerned, but this is not the case with low side windows, as the students will have their own shadows or those of the bottle racks, if high, thrown on to their work.

The width of a double bench is usually between 4 ft. and 5 ft. 6 ins., and a greater width is not desirable. If a demonstrator's table is required, this need not, as a rule, be more than 2 ft. to 2 ft. 6 ins. wide, with some 4 ft. between it and the wall. In front of this table, space should be left to enable a class to stand, observe experiments which cannot conveniently be seen at a distance, and, take notes. Wall benches for general apparatus, distillations and combustions are usually about 2 ft. wide. The extent of such benches varies a good deal and depends in some measure upon the area devoted to fume cupboards and the provision of subsidiary rooms. Plans illustrating the arrangements of the fittings enumerated will be found in Chapter VI.

Students' Benches (Design).—The working benches are the most important fitting in a laboratory, and before they can be designed the fittings must be laid out on the plan. Bench construction depends largely upon whether the students are to have individual drawers and lockers. Now, though these are usually provided, and the writer personally thinks them very desirable, the fact remains that for much junior work very little use is made of them, and they are often to be found practically empty or used for general storage of stock, for which they are not designed; or perhaps they are used by the students, but so badly kept, that they entirely fail to attain their object, which should be to inculcate a feeling of personal responsibility and habits of order and cleanliness. Individual lockers naturally add to the cost of fittings, but what is not always realized is that to stock them out properly and keep them properly involves a good deal of apparatus and attendance.

In the case of institutions of university rank, where students purchase

their own apparatus, lockers are essential, and the above criticisms hardly apply. It is quite possible to provide three lockers and drawers of sufficient size under a working place 3 ft. 6 ins. long, and if 4 ft. be given to each place, even four could be arranged, as the 11 ins. width per locker only thus available would be enough for elementary needs. Thus three or even four different sets of students can be provided with private lockers under their own working places, which location is essential if confusion is to be avoided.

It not infrequently happens that fittings are ordered from some firm of makers or that designs are prepared by the architect without sufficient information as to the scheme of work intended, which indeed may not have been matured. In this case probably two lockers are provided under each place, an arrangement which may prove very unsuitable. Though three lockers under each place may supply all the needs of a small school, say for two large forms and two higher forms of half their size, it is probable that even four will not be enough for a large school if no advanced laboratory also exists to increase the accommodation. In this event it must be decided whether to attempt a further division of the space into what will amount to "pigeon holes," to let certain forms be lockerless, or allow more than one set of boys to use the same locker.

Another matter affecting bench construction is the position and number of the sinks. Undoubtedly the simplest arrangement is to have sinks at the ends of the bench only, but as it is desirable that every worker have access to a sink without leaving his position, benches for more than two on each side should have sinks in the bench top itself. One sink, however, can serve four students, if their places all adjoin it, hence it follows that the least sinks are necessary when the total number of students on a bench is a multiple of four. The use of end sinks requires one more on any bench than when more central positions are employed. These alternatives will be made clear by a study of the diagrams, **Fig. 6 A-E.** Subject to the necessities of the case, the less drainage and service pipes in the bench the better.

Formerly all benches possessed at least two tiers of shelves along their whole lengths, but the revolt against chemical analysis as a beginners' subject and the substitution of descriptive and simple gravimetric work made the large number of bottles supplied to each student unnecessary. Recently, however, a tendency to re-introduce analysis as a means of studying chemical principles has manifested itself, and, of course, it may often happen

that the use of the laboratory for students of various grades makes bottle racks essential. If the bench length is generous, probably a single row of bottles standing on the bench itself for such student's use will be enough, but this is a matter upon which the teaching staff must advise. The absence of these racks is a great aid to supervision and lightens the general effect of the room, and their only constructional merit is that they form useful supports for running gas, water, and electric services.

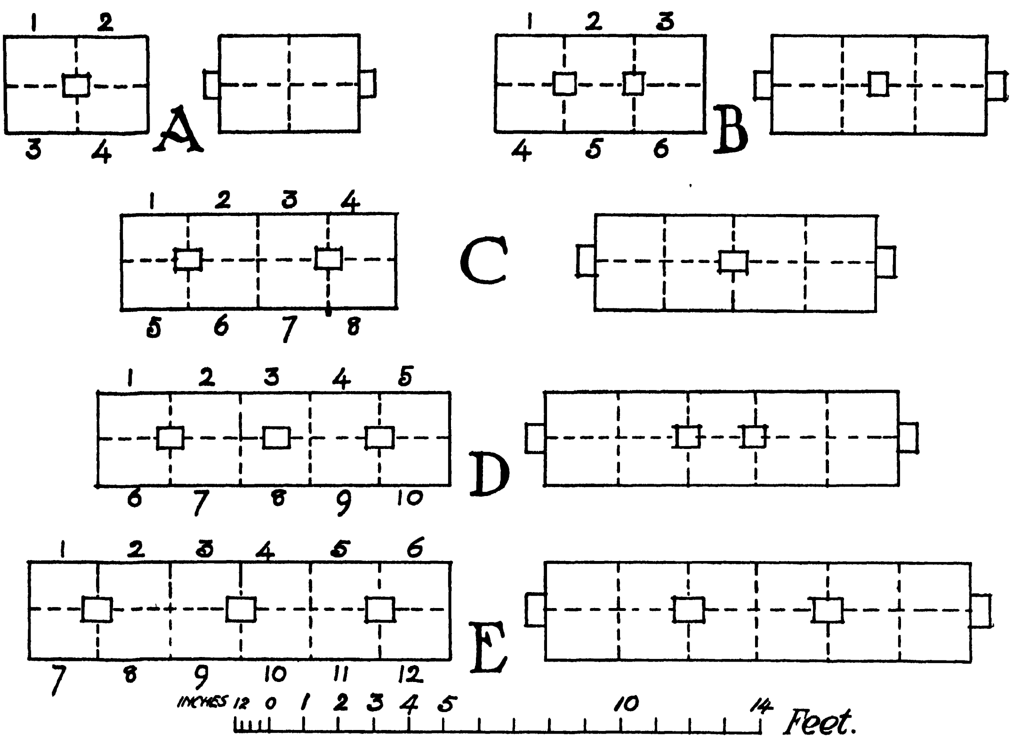


FIG. 6.—Arrangement of Bench Sinks.

Construction of Working Benches Tops.—The leading conditions governing the design of the benches now settled, details of the construction and materials may be considered. Double benches are generally 4 ft. to 5 ft, wide and the height is usually 3 ft. above the floor, or slightly less, though in certain American High Schools the height recommended is 3 ft. to 3 ft. 2 ins. The new benches at University College, London, are 3 ft., and at the most recent Oxford laboratory 2 ft. 11½ ins., while the last installed at Cambridge are 2 ft. 11 ins., which suggests that

3 ft. is a little high for school benches. The tops are usually of teak, not less than 1¼ ins. thick, but many other materials have been tried. A bench top gets very severe treatment, the strongest acids and alkalis are frequently spilt on it and local wetting and very considerable heating are common. No wood exists which is proof against all these conditions, but if wood is employed it should obviously be as impervious to wet as possible and reasonably hard. Mahogany, though not so dense and oily as teak, is occasionally used and is less likely to cast or split. In the new inorganic laboratory of University College, London, hard-pressed red tiles have been used. These have a slightly irregular surface, are jointed in portland cement and bedded on concrete on a steel frame (**Fig.** 7). This construction, much used in Germany, is also to be found in the recent buildings of Bristol University. In both these universities personal inquiries prove that these tiles are liked and do not involve much breakage of glass in the hands of those used to them. Another material employed in a number of institutions abroad, such as the Pasteur Institute in Paris, where it has stood the test of many years, is "lavee émaillée," a volcanic stone which is sawn to suitable sizes and surfaced with vitreous enamel. The makers, Mm. Flicoteaux et Cie,[1] claim that this surface is unattacked by chemicals and will not splinter. The cleanliness of such a bench top is undeniable, and probably it is not more prone to cause breakages than tiles. Further, the material is obtainable in large sheets up to about 6 ft. by 2 ft., but is somewhat expensive White is the colour usually adopted for the enamel. Whether white is the most suitable colour for a bench top requires investigation. Lead is occasionally used for covering bench tops but only for special organic work. For general purposes it is found to get very dirty and indented and rucks under heat.

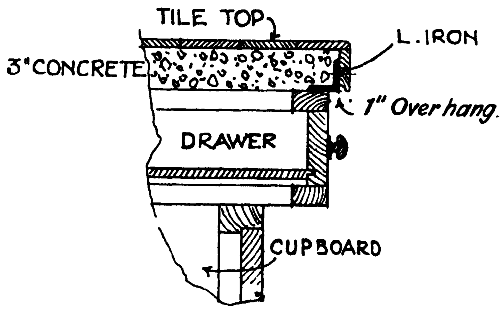


FIG. 7.—Section through bench tops, University College, London.

Bench Sinks.—Sinks are usually made of white glazed fireclay, but yellow glazed stoneware is sometimes used, as being a little cheaper. These

[1] 83 Rue Du Bac., Paris.

glazes should be free from lead. Heavy ware is desirable as breakage may involve much trouble, since laboratory sinks are not made to standard sizes and may take several months to replace. Breakages, however, with good material are of very rare occurrence. Lead-lined sinks buckle and may eventually crack with changes of temperature and become exceedingly dirty with chemicals. Prof. Armstrong recommends sinks of American white wood, the sides and bottoms without joints, the wood being pitched before they are put together, and the interior afterwards similarly treated. It is necessary to keep water in such sinks, which can be contrived by placing the outlet above the bottom, which also tends to prevent solid matter going down the drains. Sinks of this type are cheap, but are rarely used, and should not be placed in positions inaccessible for repairs.

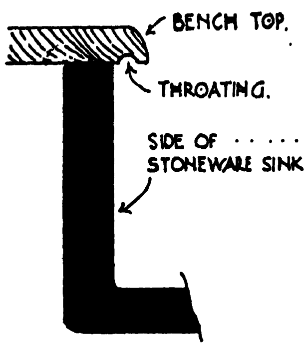


FIG. 8. — Section showing Bench Top Over-running Sink.

When sinks are not placed at the free ends of the benches, the bench top is best arranged to overrun them with a groove or throat below, to prevent water running back underneath; this makes any putty joint unnecessary (**Fig. 8**). Another method adopted at Bristol University, is to have a throat and flange made as part of the sink. This, of course, increases its cost and still leaves it necessary to have a joint in cement between the wood and pottery, and as no sink is perfectly regular, this joint is seldom satisfactory. Sinks need not be large, but those at the free ends of benches should usually be larger than those in the bench, since anything spilt on the floor will be less likely to receive attention than on the bench. Again, running the bench top over sinks, as suggested, renders a rather larger sink desirable than if this is not done. Sinks are hardly ever used as pneumatic troughs for experiments, hence they need only be regarded as receptacles for waste; a rectangular form, though generally employed, is not therefore essential. The bench sinks most recently installed for chemical work at Cambridge are bell shaped, and about 10 ins. in diameter and in depth, made of cane glazed ware with a grid at the bottom formed by perforations in the ware itself. These sinks are easy to clean and are regarded as satisfactory. As ware sinks are of some thickness, in specifying them it should be made clear whether

the dimensions are external or internal. As a general guide to sizes, 24 ins. by 12 ins. by 7 ins. deep inside is suitable for a sink at a bench end, and for sinks in the bench covered as described, perhaps 12 ins. by 15 to 18 ins. by 7 ins. deep. The usual outlet to a ware laboratory sink is a stoneware grid (no brass must be used) cemented in from the top. Spigots (outlet pieces) made as part of the sink are better, as having no joint, which always gets dirty, but are so easily broken in transit that they are difficult to obtain from makers. Spigots can also be cemented in from below (**Fig. 9**) and are satisfactory if not made to carry the weight of lead wastes. All grids in waste openings are apt to get choked at times and are best made movable but not too easily so, otherwise students may remove them and solid bodies may find their way into the drains. A perforated, slightly-tapered glazed ware plug (**Fig. 10**), the top flush with the bottom of the sink, will prove satisfactory.

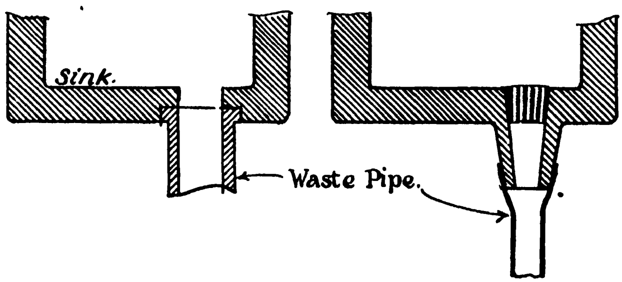


FIG. 9. FIG. 10.
Sink Outlets.

The waste pipes should be straight lengths of untrapped lead or earthenware pipe, the former dressed well over the sink spigot, suitably supported on the bench framing, and terminated with an open end bent slightly in the direction of flow in the drain.

Bottle Racks.—Some reagent bottles are usually required on a bench, but if only one row is necessary, these can stand on a strip of opal glass let into the bench top or surrounded by a thin hard wood beading. If two rows—usually the limit—are required a shelf generally of $\frac{1}{4}$ in. plate glass supported by wooden or metal ends, but sometimes of wood, or wood covered by glass or tiles, is provided. These shelves, which serve both sides of a double bench, are divided by a horizontal bar of wood, or enamelled iron, to prevent bottles being pushed through. Sometimes the whole of the frame work is enamelled iron, which has a lighter effect than wood. Such iron reagent shelves are used at Leipzig University.

The bottles for these shelves are seldom more than 6 ins. high and 3 ins. in diameter, hence 7 ins. between shelves 4 ins. wide is usually sufficient. Shelves wholly of glass should be supported below either by a wooden bar or a light T iron, unless they are exceptionally short.

Framing and Lockers.—The top of the bench should project over the framing 3 or 4 inches, and if the top rail to the framing is omitted (an arrangement disliked by joiners) things cannot stick in the drawers. The lockers should have a shelf but only over part of their area so that tall apparatus may stand in front. A bottom raised about 4 or 5 ins. above the floor should always be provided and the door should be arranged to stop against this to assist in excluding dust. Below the door toe space should be provided, though if the lockers are again recessed under the drawers, as is often done, this space is hardly necessary. Drawer and locker handles should be of hardwood; sometimes, as in the recent laboratories at Cam-

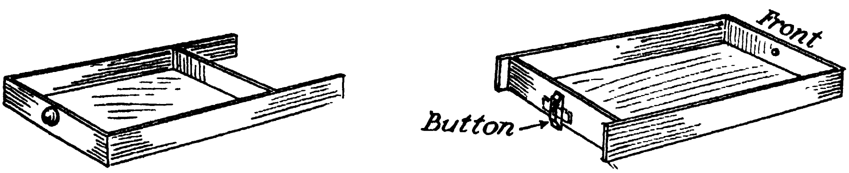


FIG. 11.—Security of Bench Drawers.

bridge, a fixed towel rail is used as a handle to the drawers. The sides of drawers are sometimes run on beyond the back to reduce the danger of pulling the drawer right out; alternatively a button may be fixed to the back which will, when vertical, catch on the framing below the drawer and prevent removal until it is turned into a horizontal position (**Fig. 11**). Drawers need not be deeper than 3 to 4 ins. and should have hardwood runners of oak. Locker fronts are often made of pitch pine but yellow deal is quite satisfactory.

As to locking drawers and cupboards, for senior students padlocks are probably best though they involve much undesirable metal work. The simplest padlock scheme is probably that instituted many years ago at Nottingham by Prof. Clowes—a single iron bar extending over one set of drawers and cupboards being secured to a hasp in the cupboard door. An elaborate system of padlocks is in use at Leipzig University. The advantage of the padlock system is that when keys are lost the padlock can be filed through and replaced at the student's expense without damage to the fitting. Young

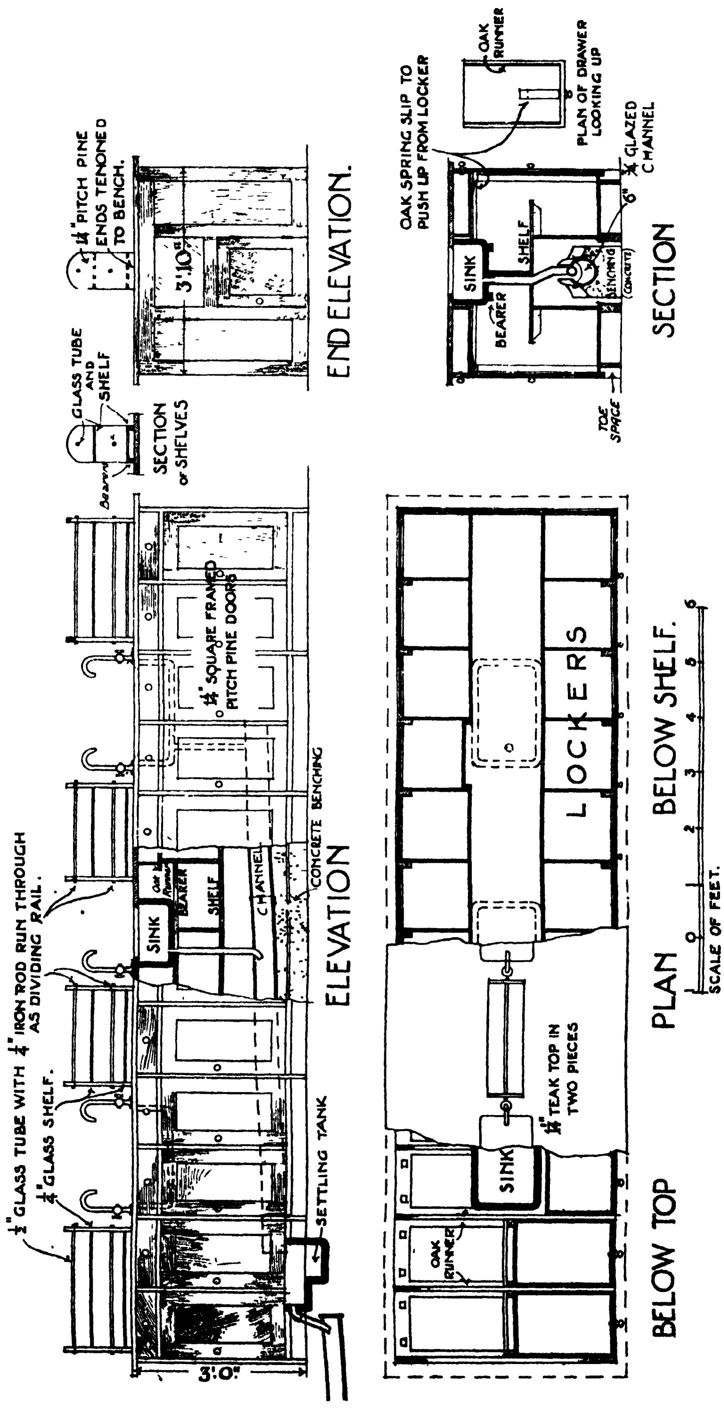


FIG. 12.—Detail of Student's Bench with Three Lockers to each Place.

[*Alan E. Munby, F.R.I.B.A.*

students should not be given keys, and the writer's experience is that a very strong type of spring lock made to one key, retained by the staff, is the best arrangement for schools, the lockers of each form being opened just before work begins, which is a very short operation if they have a distinctive mark such as a name label of a given colour. Drawers may be controlled with the key of the locker below them by a thin oak spring, which, until pressed up, engages on the framing below the drawer, the spring being only accessible through the open locker. By this scheme all drawers and lockers are secured by mere closing. This is illustrated in **Fig. 12**, which shows a working detail of a student's bench.[1]

Access to Drains.—When drains, as in the above illustration, have to run in the bench they are sometimes arranged to be themselves movable, as at Bristol University, otherwise they are most readily reached by end doors and movable panels at the backs of the students' lockers, and for a glazed ware drain such access in every third locker should be sufficient. Sometimes part of the bench is made movable. At Cambridge half of the more recent benches are arranged to draw out, leaving the top, sinks, and drainage supported by the other half; in Fischer's laboratory in Berlin, both sides of the benches draw out, leaving the centre 12 ins. only, and thus exposing the drain on both sides. In a bench of any length such possibility of movement involves appreciably enhanced expense in construction. Another way of dealing with bench drainage is to bring it to the bench top and utilize it in place of sinks. **Fig. 13** shows a detail of such a plan as designed by Messrs. Alison & Alison, Architects, of Los Angeles, who have kindly contributed the drawing. The half elevation and plan illustrate the sink at one end only. This sink and the bench drain discharging into it is shown on the end elevation and the latter also on the section. The V-shaped trough drain is of wood covered with 4 lb. lead with burnt joints. This design is used at the State Normal School, Los Angeles, described in Chapter VI.

This surface drainage method is also followed by the School House Department, Boston, U.S.A. **Fig. 14** shows a detail of the standard bench

[1] No special merit is claimed for this design, which is given as an example which the writer happened to have by him. The settling tank would normally be placed nearer the end of the bench.

adopted and is taken from this Department's Report of 1916.[1] The trough, some 9 ins. wide and 5 to 8 ins. deep, in a bench 24 ft. long, terminates with a waste pipe and mercury trap. It is made of soapstone and over it

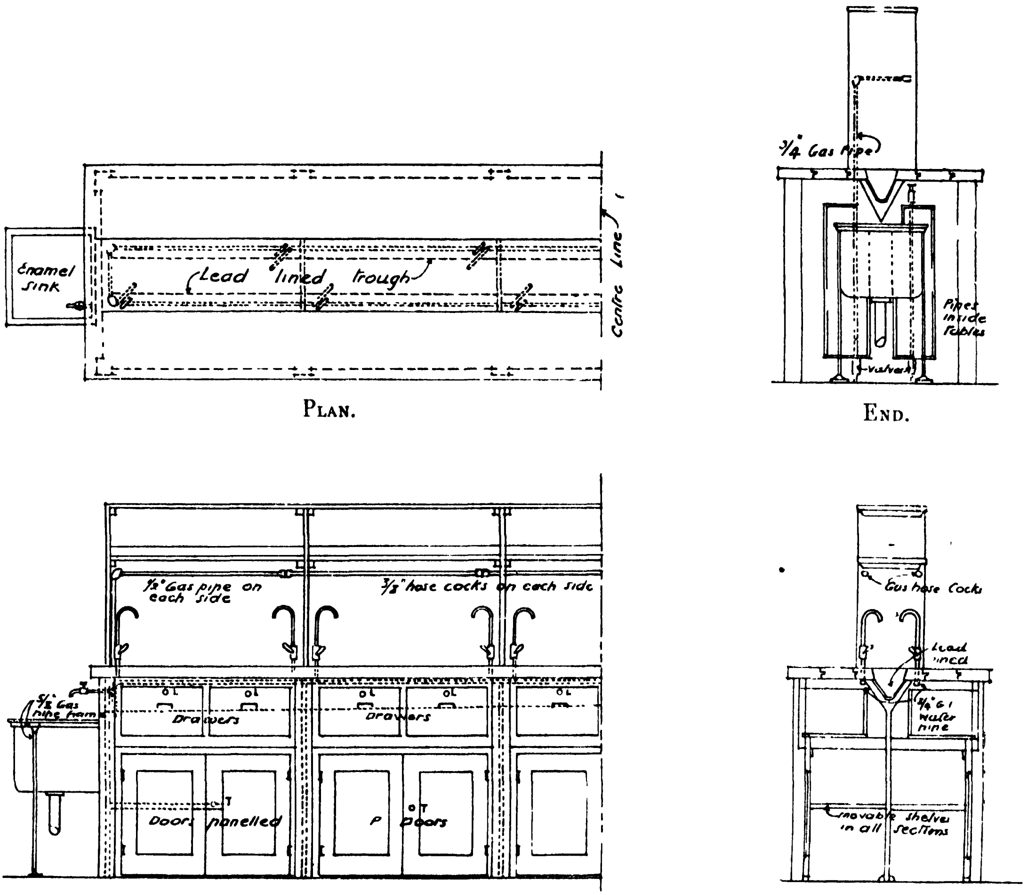


FIG. 13.—Chemical Bench used in the State Normal School, Los Angeles.

are placed the bottle shelves of plate glass. The tops of these benches are of pine.

Services.—Laboratory services will form the subject of Chapter V. It will be sufficient to say here that the method of running pipes and drains

[1] For a copy of this report the author is indebted to Messrs. Cram & Ferguson, Architects, U.S.A.

must be decided upon before joinery details are executed. The centre of a double bench or the back of a wall bench form the natural locations for services, but sometimes gas is run below the bench top in front where it overhangs the drawers, with either branch pipes to the centre (or back) of the bench where the nozzles are fixed on the bench top or with nozzle direct off the supply pipe in front; this may influence design of the bench, as space must be left for the pipes. Fume hoods on the benches are sometimes provided in the form of a metal or wood tube or boxing with a small hood 9 or 10 ins. square attached to a ventilating trunk in the bench. A very efficient ventilation system is required for these hoods and usually a liberal supply of fume cupboards is preferable. Trumpet-shaped bench vents, as used (but in one room only) on the benches at Leipzig University, are illustrated on page 44.

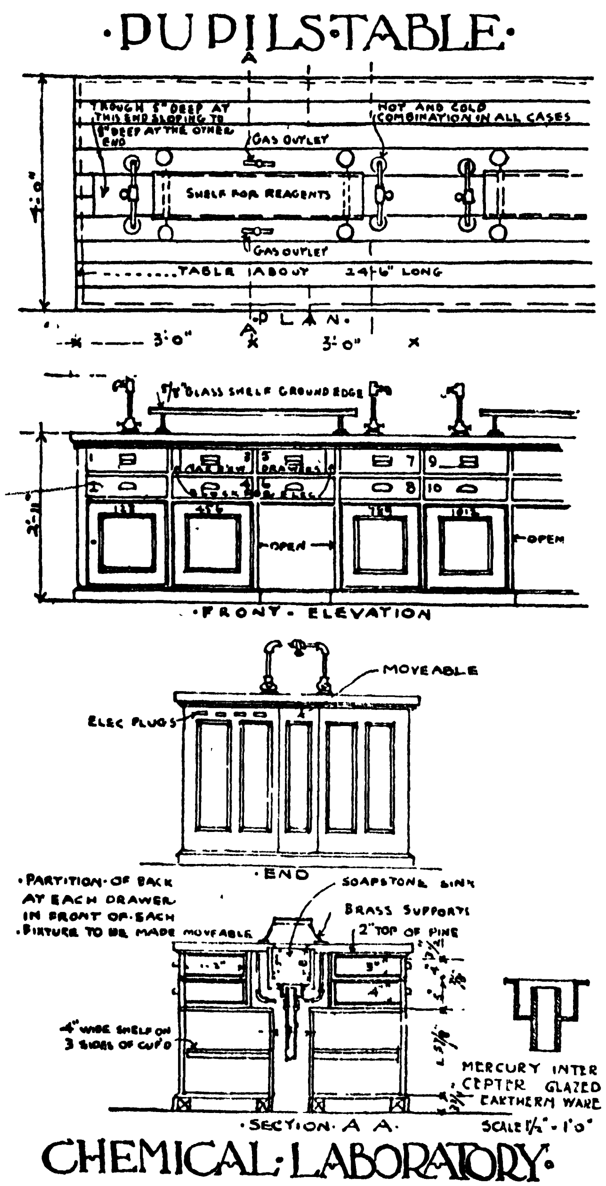


FIG. 14.—Standard Chemical Bench adopted by the School House Department, Boston, U.S.A.

Surface Treatment.—The tops of benches when of wood require frequent treatment for their protection, paraffin wax, beeswax and similar "fillers," either melted and ironed in or dissolved in suitable organic liquids, are frequently used but should not be so applied that hot bodies produce a mark due to melting of excess of these ingredients. Boiled linseed oil applied hot in a thin layer with successive applications only after complete absorption is still one of the best protections known, the oil drying into a resinous and insoluble body in the pores of the wood. This treatment should be repeated at intervals, say each vacation.[1] This subject needs and deserves investigation, probably some treatment under pressure could be found which would render many of the less costly woods available for bench tops. As to the framing nothing is nicer than to leave wood which possesses a grain to mellow without any surface covering, but the doors and exposed framework of the benches are apt to get dirty, hence oiling to fill the pores, waxing, staining or varnishing, and sometimes painting, are resorted to. In Fischer's Berlin laboratory the tops are oiled and the other exposed work painted grey.

Waste Boxes.—Some provision for solid refuse such as filter papers, broken glass and the like, is necessary, on or near all chemical benches. This often takes the form of a box or tray of wood or metal pitched inside, and should have a definite location under or at the end of the bench. If large, or not in much evidence, these receptacles tend to be left unemptied for too long. The daily refuse from a bench is not great and the system adopted at Bristol and University College, London, where a semi-circular trough of well-painted sheet iron about 6 ins. in diameter and 12 to 18 ins. long is fixed to each end of the bench, has much to recommend it. One end is left entirely open and from this the refuse can be rapidly swept into a pail daily when the students leave.

Fume Cupboards.—Fume cupboards or draught closets are required in all laboratories where noxious gases are produced. These cupboards almost invariably consist of a wood-framed glazed case in which the experiment is performed, with some special means of ventilation. The most usual and probably best place for these cupboards is in the windows, as good light is essential. Such a situation in a low room dependent upon its side

[1] Aniline black is also a good protector and is used on ordinary pine for bench tops in some American schools, with a waterproof lead paint finish.

windows might seriously reduce the general illumination, but with a lofty window the cupboard top can terminate at the transom, leaving the upper part of the window unimpeded. In practice it will be found that chemical laboratory windows, near the bench level, can never be opened on account of draughts affecting flames and producing other disturbing causes, hence no detriment results by fixing this lower sash. These cupboards may vary in size a good deal but should not generally exceed 2 ft. from back to front for ordinary work, and should be high enough for tall apparatus. They are usually between 3 and 6 ft. in length and the sash should be able to be thrown up to a height of not less than 2 ft. 9 ins. The glazed top generally slopes up like a lean-to roof. The front, which opens, is hung as a sliding sash, either with pulleys and weights in the wood framing like an ordinary window, or with a single pulley and counter-weight fixed on the back wall or in some other convenient position, in which case wire rope is generally employed in place of cord. The life of this rope depends very much on the bending to which it is submitted, hence pulleys should be of large diameter. If cords are used they should be well soaked in melted vaseline before they are fixed, which will considerably add to their durability. The use of a single wire cord reduces the dimensions of the wood framing, but is more dangerous in the event of a breakage of the line. Various racket devices have been employed for the sashes to obviate the use of lines and pulleys, but they are not usually reliable and the principle is unsuited to sashes of any magnitude. At Leipzig part of the casing which secures the sashes is made movable so that they can be readily cleaned inside, as shown in **Fig. 15. Fig. 16** gives a plan, section, and elevation of the cupboards used in Fischer's laboratory in Berlin, from which the construction referred to will be readily understood. The double outer windows appearing in the section are provided to meet climatic conditions, and have no chemical significance. All

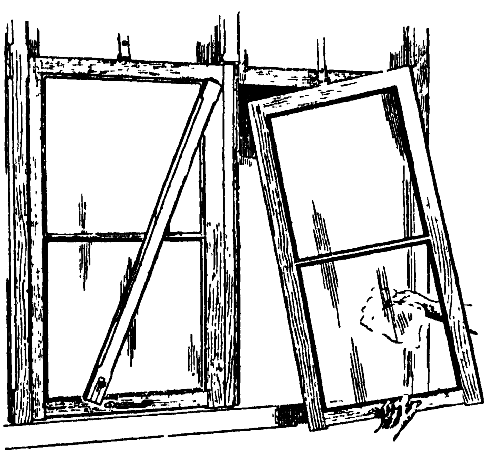


FIG. 15.—Detachable Window to Fume Cupboard, Leipzig.

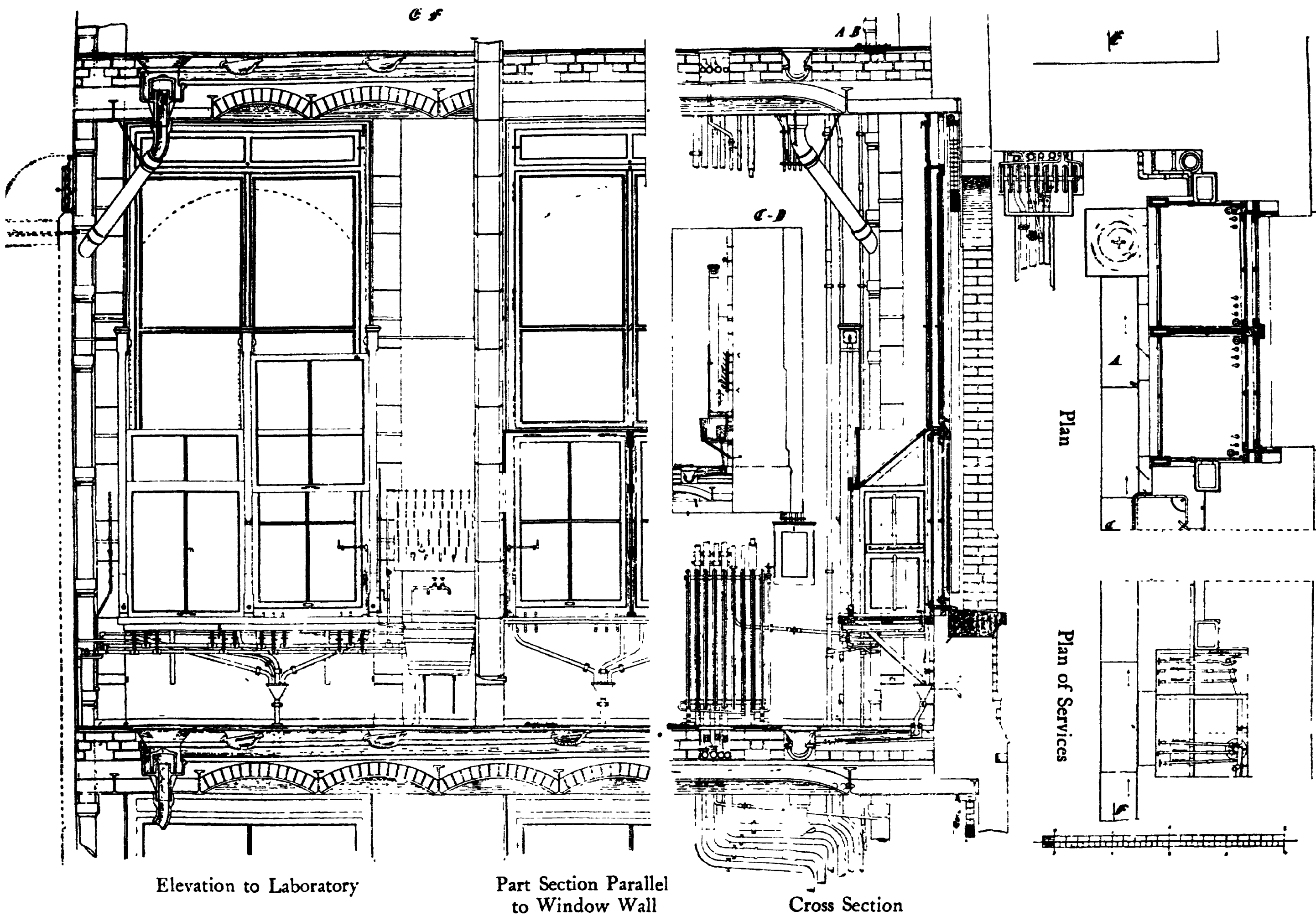


FIG. 16.—Fume Cupboard, Chemical Institute, Berlin.

[To face page 36.

glazing should be fixed with wood beads to facilitate renewals, if such glazing to the sashes be done in the ordinary way, but on raising the sash a space is formed between the glass and the framing above, as shown in **Fig. 17,** which often allows fumes to escape. Various devices (none very successful) have been used to overcome this, but it may be largely remedied by using plate glass fixed at the corners by metal strips practically flush with the inside face of the wood frame (**Fig. 18**).

The bottoms of fume cupboards are often tiled. Such a surface is found in many recent laboratories, as at Leipzig, Berlin, Bristol University, and University College, London, and is probably the best material. A very close-grained sandstone is not inappropriate, though it will stain ; slate cracks

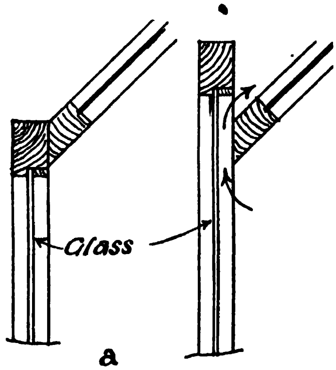


FIG. 17.—Section showing Leakage when Fume Cupboard Sash is raised.

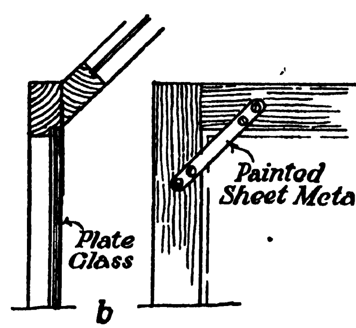


FIG. 18.—Method of Reducing Leakage by fixing Glass on Internal Face.

under heat, otherwise it is very suitable and is largely used. Glazed fireclay slabs are sometimes employed and have recently been used at Harrow School, two slabs 2 ft. 11 ins. by 2 ft. 3 ins. and $2\frac{1}{2}$ ins. thick forming the bottom of each cupboard. While very cleanly and chemical proof, this surface is never quite level, is somewhat likely to cause breakages among young students, and if chipped cannot be repaired. Where economy is an object, a bed of concrete finished with a fine cement face, subsequently coated with Brunswick black, would make a fireproof and satisfactory base, holes for supplies being formed with removable wood plugs in the concrete during making.

Reference has been made above to the fume cupboards at Leipzig University. In these, the flue opening placed in the wall is $35\frac{1}{2}$ ins. above the base of the cupboard, the back of the roof against wall or window being

5 ft. 7 ins. For general work the width of the cupboard is 21 ins., but for organic work $27\frac{1}{2}$ ins. In the University laboratories at Cambridge the cupboard tops are flat and not of glass, but of uralite or similar fibre and cement compound in two horizontal layers, with an air space of some inches between connected to the exhaust flue; the lower or ceiling sheet is pierced with numerous holes about an inch in diameter through which the fumes are drawn from any part of the cupboard.

Evaporation Cupboards.—Cupboards of a special type are sometimes used for evaporations. They are constructed like ordinary fume cupboards, but the bottom consists of a copper vessel fed with water so that its water-level remains constant. On this, supported by suitable rings, the vessel containing the liquid to be evaporated is placed. The water is heated by steam or a gas jet. These cupboards are often only 18 ins. square and want a good draught to remove condensed moisture. They are usually placed in rows of three or four to economize gas and water service. Frequently, however, evaporations are carried out in ordinary fume cupboards, and one of the best methods (devised, the writer believes, by Prof. Donnan) consists of a stand over which is placed a sheet of silica upon which a flame plays. The vessels in which evaporation is effected being supported under this sheet, the free surface of the liquid is thus heated and vaporized without any spurting. All fume cupboards require a gas supply and usually water is provided, in which case some form of waste is necessary. This is best made as an opening about 3 ins. in diameter in a piece of glazed ware let into the bottom of the cupboard. Gas and water taps and as much as possible of the pipes must be kept outside the cupboards. The ventilation of these cupboards is considered in Chapter V.

Side Benches.—Several public benches in a laboratory are a great advantage and may be a necessity if the adjuncts in the way of rooms for special work are lacking. Under some of these benches, cupboards and shelves will be desirable for storing things in general use. These benches do not get the same drastic treatment from spilt chemicals as do the students' benches, but hardwood tops treated in a similar manner are desirable. Space may sometimes be found for such benches between fume cupboards in the windows. Even when a combustion room is provided, every laboratory should have some bench area of incombustible material, commonly fine sandstone, for dealing with bodies too hot to be placed on wood. Such benches will

be described under combustion rooms in this chapter. No rules can be laid down for side benches or their fittings, but for junior work the apparatus to be stored consists largely of heavy stone troughs about 14 ins. in diameter and 6 ins. high, glass cylinders about 2 ins. in diameter and 10 ins. high, iron stands—vertical rods, 18 ins. to about 30 ins. long, on heavy feet—for holding apparatus, and small dishes, crucibles, corks, filter-paper, and the like, for which drawers are most suitable.

Drying Ovens.—It is constantly necessary to dry in small glass vessels solids produced by precipitation, and for this purpose a set of drying ovens —pigeon-holes with doors—round which steam circulates in an outer jacket, are provided, and with these ovens a still, for producing distilled water, is generally combined. If there is a steam supply this is used as the source of heat, otherwise gas is employed to boil water in a tank forming the bottom of the range of ovens. In either case the steam is often condensed by finally impinging upon metal surfaces cooled by water, and is collected in a tank of tin lined copper or in a large stoneware or glass bottle. In these ovens, which are made of copper, the individual compartments vary in size from about 6 ins. to 12 ins. each way, and are made in sets, but in order to dry lengthy apparatus, it is often arranged that one or more vertical tiers have movable trays as bottoms, and can thus be converted into a single high oven. The number and size of these ovens depends on the work proposed. In the Chemical Institute, Berlin, serving the two large organic laboratories holding forty-eight students each, there is a group of 25 ovens, half of them measuring 6 ins. by 6 ins. by 7 ins. high and the remainder 13 ins. by 6 ins. by 11 ins. high inside.

Demonstration Table.—If a demonstration table is provided—a provision more usual in schools than in university laboratories—it should be raised 6 ins. or 8 ins. on a platform and resemble a lecture table. Usually a table 10 ft. or 12 ft. long and 2 ft. wide, or even smaller, is sufficient, unless it is to take the place of a lecture table altogether. Gas, water, and a sink are requisite and some drawers and cupboards; details as to which are given under the section on lecture tables, page 41.

Blowpipe Table.—Mouth blowpipe work is generally done on the working bench, but when a foot bellows is required a special blowpipe and a more ample gas supply demand a specific place. This may be on the combustion bench or on a separate movable table 2 ft. to 3 ft. square, with its

top covered with sheet-iron or lead, dressed over a fillet at the edge to prevent hot glass fragments falling on to the floor. The bellows are sometimes fixed to the table framing. This table may be advantageously 2 ins. or 3 ins. lower than the working benches.

Shelves.—A great deal of wall shelving is required in a laboratory, mostly for bottles not wanted on the benches, and if the room is a large one, duplicate sets of such reagents may be necessary. No shelves should be wide enough to allow one bottle to stand behind another, and a surprisingly large proportion of bottles will be found not to exceed 3 ins. in diameter, a Winchester quart (a tall 2 qt. bottle) will stand on a $4\frac{1}{2}$ in. shelf, a large aspirator on one 9 ins. wide. It is not desirable to risk the use of adjustable shelves for this purpose, though alterations are frequent, but ledges or brackets may be fixed with brass screws instead of nails and glue which will help modifications. Shelves, as a rule, do not need backs but a wood fillet may be advantageous to prevent delicate apparatus being carelessly thrust against a hard wall surface. Wall shelves are usually of wood, sometimes overlaid by glass or less frequently by tiles. A set of detached shelves specially designed for aspirators is described on page 60.

Stools.—Laboratory stools should be provided for all students, and these should be light and portable. If the horizontal framing bars holding the legs together be placed at different heights, not only can the legs be rather thinner but these bars may be used as steps for reaching apparatus. The bars and the seat should be in hardwood. Prof. Francis in his laboratory at Bristol uses stools which are oblong lidless boxes about the size of an ordinary stool. These are found useful as temporary stands or tables, to carry apparatus for special experiments and also serve as trays for moving bottles required for filling.

The Lecture Theatre.—A lecture room may vary from an ordinary class-room with a bench suitable for demonstrations, to a theatre to hold a large audience, with every modern elaboration for experiments, and the area allowed per head, naturally, varies somewhat with the character of the room, as does the cubic space necessary. Large rooms generally require two floors, being often entered on one at the lecturer's level, and on the next above, at the upper tiers of the students' raised staging. The secondary school basis of 18 sq. ft. per head in a class-room will, as a rule, easily serve for a room of this character. For large numbers, entrance and exit doors require careful arrange-

ment; the main doors are usually placed on the floor level, opening upon the space between students and lecturer; direct access to the preparation room behind the lecturer is also necessary. The staging for the students' seats should extend the whole width of the room, and the window light for the desks be, of course, on the left of the students, if confined to one wall. The space between the front seat and the lecture table should be 4 ft. to 6 ft., and between the other side of this table and the wall, about the same. Efficient means for hearing, seeing, and writing are the essentials of a good lecture theatre; the first deals with matters beyond the scope of this book, but it may be said that the chief things to avoid for acoustic success are large flat and hard surfaces facing the lecturer, great open space behind or above him, and unnecessary space above the students, though this is less important. The speaker's voice should go direct to the audience with as little disturbance on the way from recesses, deep window and door reveals, and the like, as possible. Splayed angles at the end of the room will prevent seats near the corners being worse than others for hearing, and any ventilation currents should set from the lecturer towards the audience. Raised staging is a great help to hearing as well as seeing, and in a large room assists in preventing echo.

In addition to the lecture table and seating, ample blackboard and diagram space, a fume cupboard near the lecture table, shelves for reagent bottles, and a demonstration lantern and its screen are necessary.

A lecture table may vary from an ordinary elongated table, or bench, supplied with a few drawers, and with gas and water, to an elaborate fitting suitable for every kind of experiment. The table is usually 3 ft. wide and 3 ft. high, but in the American schools of Boston only 2 ft. 8 ins. high, and as space is never amiss, its length is generally the width of the room, less suitable passage ways between its ends and the walls. The side facing the students is often merely panelled, but since the full width is not entirely required for drawers and cupboards, it is possible to introduce glazed cupboards for keeping specimens, pigeon-holes for class note-books and the like, on the students' side.

Fig. 19 shows a detail of a lecture table at Westminster School in which such arrangements exist, while **Fig.** 20 gives a detail of the lecture table for chemical and physical work, taken from the Boston Schoolhouse Department's report, where part of the side towards the students is used for storing

maps. A very deep sink is supplied and a slate slab for insulating electrical apparatus. Sometimes, as at University College, London, a space immediately below the top on the students' side, about 5 ins. high by 3 ins. wide, is enclosed by a continuous series of hinged flaps in lengths of 3 ft. to 4 ft. wherein electric supply terminals are placed at intervals, allowing cables to be fixed and run in this enclosure to any part of the table (**Fig. 21**).

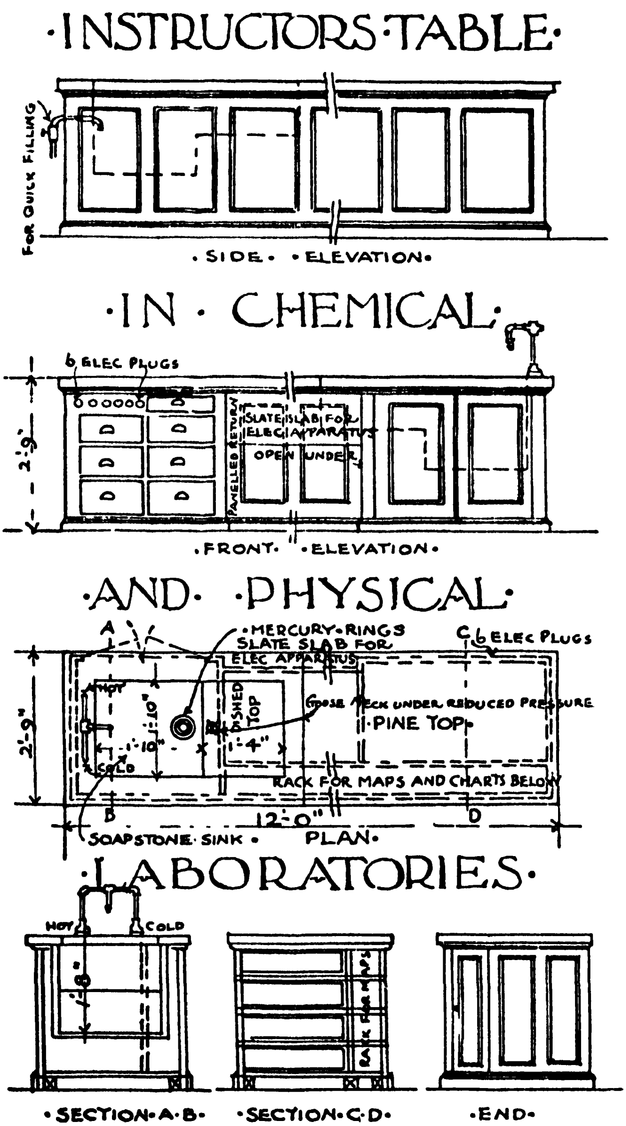


Fig. 20.—Standard Lecture Table for Chemistry and Physics used by the School House Department, Boston, U.S.A.

On the lecturer's side the whole front is sometimes filled with drawers and cupboards, though, if the table is a long one, an open space or spaces near the centre are often left which are useful for retort stands, rubbish boxes and anything not requiring better accommodation. The drawers should vary in size, one or two may be only a quarter of an inch deep and divided for rows of lantern or microscope slides,[1] others slightly deeper for storing thermometers, a few small but deep drawers for such things as dusters and

[1] Lying flat the former slides are 3¼ ins. square, the latter 3 ins. by 1 in.

cotton waste, and compartments in larger drawers for valuables, such as platinum, will be found useful. Unless the optical lantern is permanently located otherwise, a cupboard large enough for its reception will be valuable in the lecture table, and 4 ft. will not be too great a length to provide for this purpose though the requisite width may not exceed a foot. Occasionally glass panels are placed on the students' side as backs to the cupboards to illuminate their contents. It is desirable to have a specific place for a couple of compressed gas cylinders. If small these can stand vertically in one of the open recesses with their fittings and gauges within easy reach and sight of the lecturer ; if large they must lie on the floor under the table, and may occupy space of very little value for other purposes. It was formerly the custom to provide a trough in the table with glazed ends for collecting gases over water. Such a trough is very seldom used, can only be seen by a limited number, and its expense may well be avoided, apparatus on the

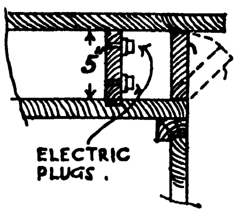


FIG. 21.—Section showing Run for Electric Wiring to Lecture Table, University College Chemical Theatre, London.

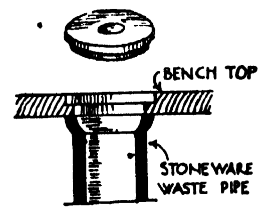


FIG. 22.—Fume Exit to Lecture Table Top.

table taking its place. A mercury bath—a small special trough for holding mercury instead of water—is another feature found in more elaborate examples which may well be dispensed with in favour of loose apparatus. At least one, and in a long table two, sinks are required, which are generally placed on the table itself, but may be external adjoining its ends. If the table is very long or for any reason carried through to the side walls, flaps should be provided to admit of ready access to the front, and these are especially desirable if the lantern is to be operated, from the space between the table and the audience, by the lecturer. The main part of the table top is usually of teak, but it is an advantage to have a limited area a few feet in length made of some incombustible material, such as tiles on concrete, sandstone, or merely fine concrete, for experiments involving much heating. Occasionally a small area is covered with lead for experiments involving

strong acids. The services necessary are often extensive; in addition to gas and water, electricity for experimental uses is desirable and often involves space for a small switchboard and heavy cables. An efficient down draught is most necessary unless the fume cupboard in the room is to answer this purpose. On the table, this generally takes the form of a 3 in. or 4 in. earthenware pipe connected to the exhaust system or special flue and terminated on the table by a sunk circular cap (**Fig. 22**). Occasionally this takes the form of a rectangular area, a foot or more square, provided with a wooden grid below a movable cover flush with the table top. The apparatus is placed on this grid, which has a funnel-shaped attachment to the exhaust system. Sometimes a pipe made of well painted sheet-iron and bent over at the top is inserted into the draught hole. This pipe terminates with a trumpet-shaped mouth over the vessel emitting fumes. Such an arrangement (used, however, on the students' benches) at Leipzig is shown in **Fig. 23.**[1]

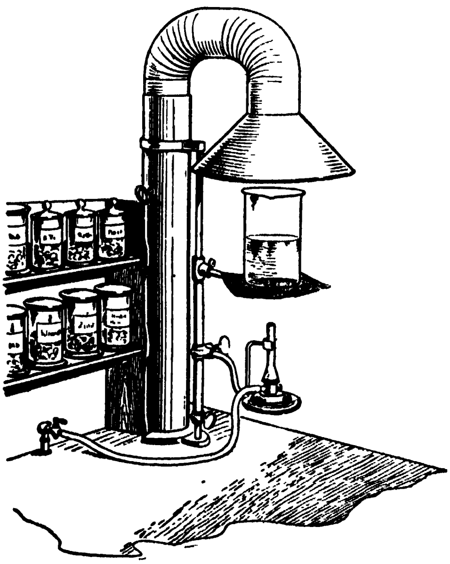


FIG. 23.—Fume Pipe for Benches or Lecture Table, Leipzig.

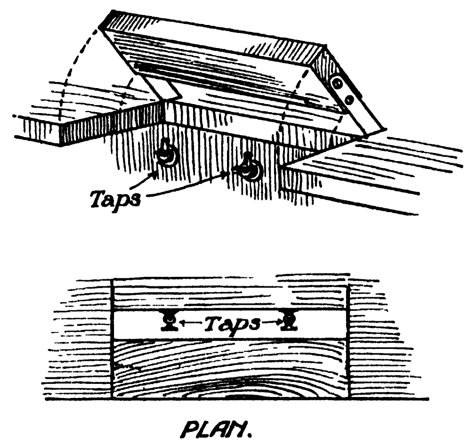


FIG. 24.—Hinged Flap to Lecture Table Top over Supplies.

A very useful protection to supply-nozzles is used at some institutions: a small section of the lecturer's edge of the table over each group of service cocks is hinged and a slot is provided behind, below which the nozzles stand vertically; the slot is about $1\frac{1}{2}$ ins. wide and 12 ins. long (**Fig. 24**).

[1] Taken from Dr. Beckman's account of this laboratory.

Another feature which might be introduced is a mirror set at an angle over apparatus to enable students to observe horizontal surfaces by reflection, as, for example, the reaction of liquids in a porcelain dish. A mirror has been so used as a piece of apparatus, but a section of the table top, say 18 ins. square, might be hinged parallel to the length of the table on the lecturer's side and faced with silvered glass below for this purpose.

An ingenious "footlight" arrangement for illuminating table specimens is employed by Prof. Kent in his lecture table at Bristol University, and, though in the Physiological Department, may be described here as being generally applicable to any table. On the students' side the whole length of the top is hinged in sections 3 ft. to 4 ft. long and about 6 ins. wide; below these lids, in a continuous recess, are electric lamps which can be turned on in pairs. The under surface of the lids is painted white and can be supported by hinged arms at a suitable angle, thus reflecting the light on to the object on the table, while screening direct rays from the audience. **Fig.** 25 shows this arrangement. This lecture table is of further interest as being entirely movable, and is arranged in four sections on casters, to admit of which the various services are made detachable by the use of suitable unions.

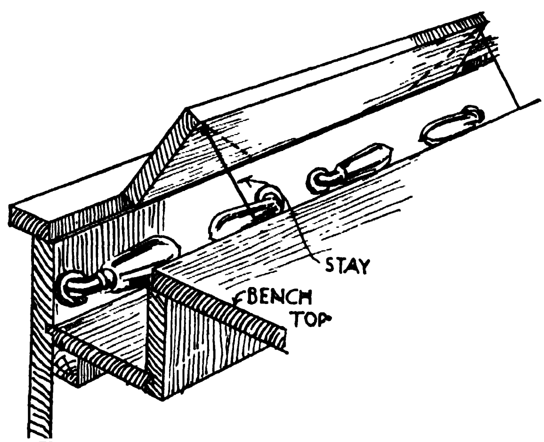


FIG. 25.—"Footlight" Illumination on Lecture Table as used at Bristol University.

One of the most elaborate lecture tables in existence is that at Fischer's laboratory in Berlin, which is no less than 60 ft. long and runs the whole width of the room. This table is 2 ft. $7\frac{1}{2}$ ins. wide, 5 ft. 5 ins. from the back wall, and 6 ft. 7 ins. from the audience. It has hinged flaps at each end and in the middle; a pneumatic trough about 3 ft. by 18 ins. by 2 ft. deep with glazed ends; a mercury bath 2 ft. 4 ins. by 1 ft. 8 ins. by 8 ins. deep; a sandstone area 3 ft. by 1 ft. 10 ins. for furnace work; two lead-covered areas 3 ft. 8 ins. by 2 ft. 1 in.; two down-draught flues 6 ins. in diameter with slate grids at their mouths; six other $1\frac{1}{4}$ in. exhaust vents in

lead ; twelve waste pipes ; twenty-four single gas cocks, two for heavy and two more for very heavy work ; one exhaust (water) pump ; six vacuum cocks ; one pair of leads for six amperes, four for twenty, one for twenty-five, and one for 400 amperes for electric furnace work, with appropriate switches and resistances. At Leipzig, supplies of hydrogen, oxygen, nitrogen, and carbon dioxide are arranged to the main lecture theatre table from an adjoining room.

Blackboards.—Extensive blackboard surface is required in the centre of the wall behind the lecturer, and as sufficient wall area within reach cannot

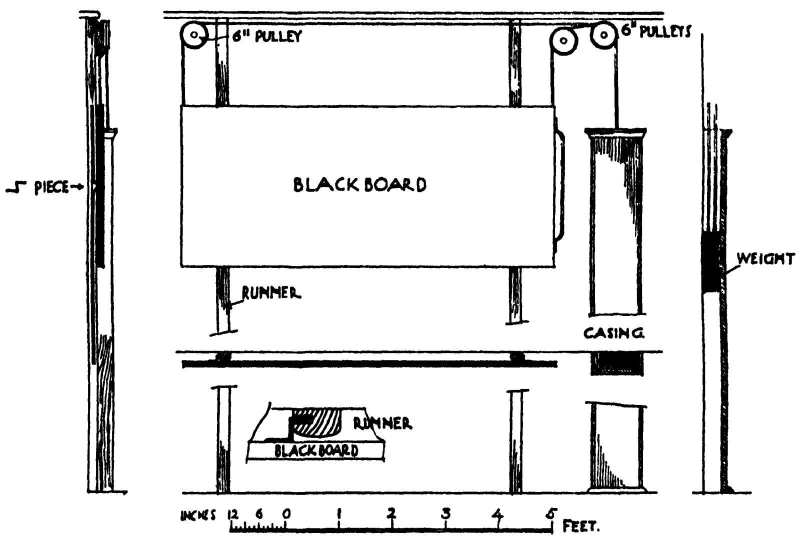


Fig. 26.—Elevation, Plan, and Sections, Kelvin hung Blackboard.

be usually devoted to this alone, boards almost invariably slide. They may be arranged as single sashes with weights ; as a pair of sashes, one balanced against the other ; as a Kelvin suspension with one weight only, as in **Fig. 26**; as a continuous prepared canvas on rollers ; or as a series of boards one behind the other sliding horizontally. As the fume cupboard is generally placed to be near the lecturer and in view of the audience in the centre of the wall behind the table, blackboard surfaces in front are for this reason wholly movable, but if no fume cupboard exists, the writing surface may be formed in the wall with a single board sliding over it. If the Kelvin principle is used, large machined pulleys at least 6 ins. in diameter, preferably on ball bearings, are necessary to approach the theoretical effect that the

board should be moved with equal ease for any position at which force is applied to raise or lower it. The best material for boards is probably black pot glass—the term "pot" meaning that the glass is black all through and not merely surface treated. The working down of surfaces of glass or slate to a proper condition requires care, as if too rough they will be difficult to clean, and use a great quantity of chalk. Roller boards are used at some institutions, and consist of a prepared canvas resembling a tarpaulin on two horizontal rollers as an endless band, similar to a kitchen towel. A narrow wooden trough to catch chalk dust is sometimes fixed horizontally below the boards, but if absorbent pads are used for cleaning in place of dusters this is hardly necessary.

Diagram Screens.—Diagrams may be permanent or temporary. A few, such as atomic weight and physical constant tables, may always be required and a permanent place might be designed for them. Temporary diagrams may only be up for a single lecture, and for these ready accessibility is therefore necessary. If the room is lofty and a diagram room can be provided above the preparation room behind the lecturer, this display could be made by providing suitable doors or slots in this wall through which the diagrams could be pushed, or a couple of vertical rollers might be inserted in the wall at a sufficient distance apart carrying an endless canvas to which the sheets could be fixed in the diagram room and then wound round to face the lecture-room audience. The writer does not know of any such arrangement, but it would utilize a very inaccessible piece of wall area. The usual practice is to have skeleton screens composed of flat laths and tape which can be lowered and raised by cords and pulleys for the attachment and display of diagrams; these screens need not necessarily be against walls but may be suspended from the ceiling somewhat nearer the audience when the accommodation is for sheets which do not require detailed explanation with a pointer. Prof. Kent of Bristol has a vertical iron column in one corner of his room carrying a number of triangular frames covered by coarse canvas. These frames swing on the column on a verticle axis and give a very extensive area for diagrams which are turned round out of the way as they are finished with (**Fig. 27**).

Fume Cupboard.—The fume cupboard behind the lecturer usually opens by a sliding sash on both sides so that the apparatus may be either prepared or removed by the assistant in the adjoining preparation room

without entering the lecture room. In other respects it resembles the cupboards already described, but the service supplies to it may usually be somewhat curtailed, as it is chiefly used as a receptacle for apparatus which is not further required.

Lantern.—The optical lantern plays such an important rôle in lectures,

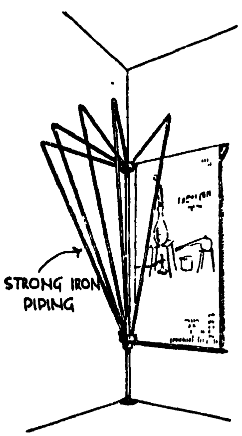


FIG. 27.—Skeleton Diagram Screen from Prof. Kent's Lecture Theatre, Bristol University.

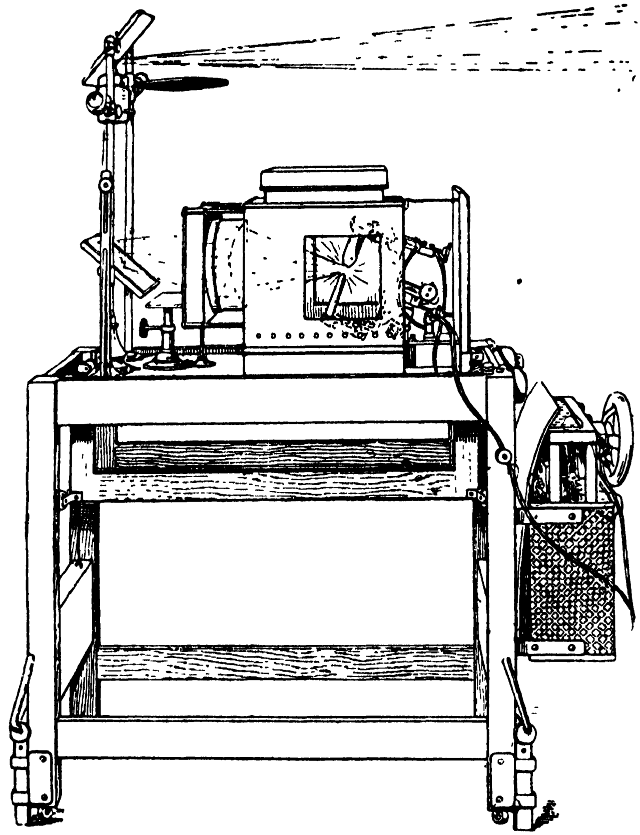


FIG. 28.—Lantern and Table at Leipzig.

that though strictly a piece of apparatus it must receive mention. The modern lantern is used for ordinary slides, apparatus, and (with a suitable attachment in place of the ordinary objective) for microscope slides, for which it is generally required in another position nearer the screen. It may be expected that the chemical changes amenable to microscopic photography will ere long require the installation of a cinematograph lantern for their demonstration.

When the lecture centres round the lantern's exhibition, there is no better place for it than at the level of the centre of the screen well back in the raised staging of the audience, but it is usually wanted intermittently, perhaps only for a few minutes, and may have to be operated by the lecturer himself, hence, for many students' classes it is placed on the lecture table near one end, to illuminate a screen fixed anglewise in one corner of the room on the lecturer's side, or a special movable table is used, placed between lecture table and the students' seating. **Fig.** 28 shows the lantern and stand used at Leipzig. In this design, steadiness is obtained by the release of a couple of stilts when the position has been fixed, which, by resting on the floor put two of the casters out of action. In this example, by the use of two plain mirrors, the picture is thrown on a screen behind the lantern instead of in front. A simpler form of stand made by the Kewaunee Manufacturing Co., U.S.A., is shown in **Fig.** 29.

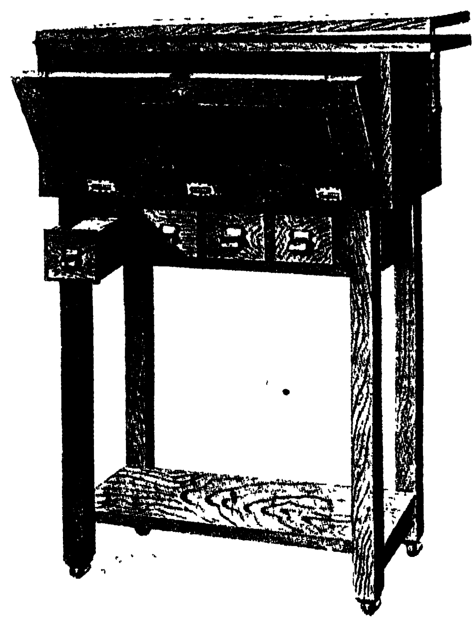


FIG. 29.—Lantern Table by Kewaunee Co.

The best of all screens for a lantern is a flat wall surface finished in hard plaster and distempered with "whitening" (chalk); paper and fabric screens waste much light by transmission, though they must often be used when a wall is not available or is unsuitably placed. For short ranges, often very convenient, much distortion may occur with ordinary short focus lenses, which might be corrected by the use of a saucer-shaped screen, allowing the picture to appear on a curved surface. For pictures 4 ft. to 5 ft. in diameter it should be possible to construct such a screen of papier mâché or other light material.

Lecture Room Seating.—Though some lecturers prefer to look down on their audiences, sight and hearing is always better when raised tiers are

provided, as the voice tends to be thrown up, and warm currents of air from the auditors further tend to accentuate this deflection. A view of the lecture table top is necessary for all experimental work, and it is chiefly for this reason that staging is used. This should be arranged to allow each row to just see over the heads of those in front, and if so arranged, it will be found that the heights of the tiers are not all the same, those at the back being greater than those in front. The principles governing these heights have been worked out,[1] and to apply them it is necessary to set up a section to scale through the tiers and their seats. Before this can be done, the room must be planned and the following decided: the width back to front of each tier, the height of the seats above the tiers, the distance of the front seat from the lecture table, and the height of the lecture table. A number of vertical lines are then drawn, the width of the tiers apart, but to pass through the centres of the seats, and the height of the lowest seat above the floor, marked off on the vertical nearest the lecture table. If this seat is made an inch or two lower than the rest, this will quite appreciably decrease the necessary height of the staging at the back. Above this lowest seat level 2 ft. 9 ins. is marked off vertically to give the level of the sitter's eye, and a further 6 ins. to clear the top of his head, through which point a line is next ruled to the centre of the table top, and back to the vertical line cutting the centre of the seat behind. The level of this seat will be 2 ft. 9 ins. below this point of intersection, and at the decided distance (16 ins. to 18 ins.) below this seat will be the first tier level, above which the desk (usually provided as a shelf attached to the back of the seat below) should be 29 ins. to 30 ins. The point of intersection of the line to the table clearing the lowest student's head with the vertical through the second seat, gives the eye of the second tier student, and 6 ins. above this, as before, a line from the lecture table continued back, will, on the next vertical, give the position of the third tier student's eye, and so on. A slight tilt on the seats will much add to comfort by bringing part of the weight of the body on to the thighs, and thus decreasing the weight per unit area; the backs and desks should also slope slightly, the accepted angle for the latter being about 15 degrees. **Fig. 30** shows a

[1] Scott Russell, Edinburgh, "Phil. Jour.," 1839: "The line touching the edges of seats in section is called an 'isacoustic curve'". "Acoustics in Relation to Architecture and Building," Roger Smith, about 1870. "Design and Equipment of Chemical and Physical Laboratories," T. H. Russell, 1903.

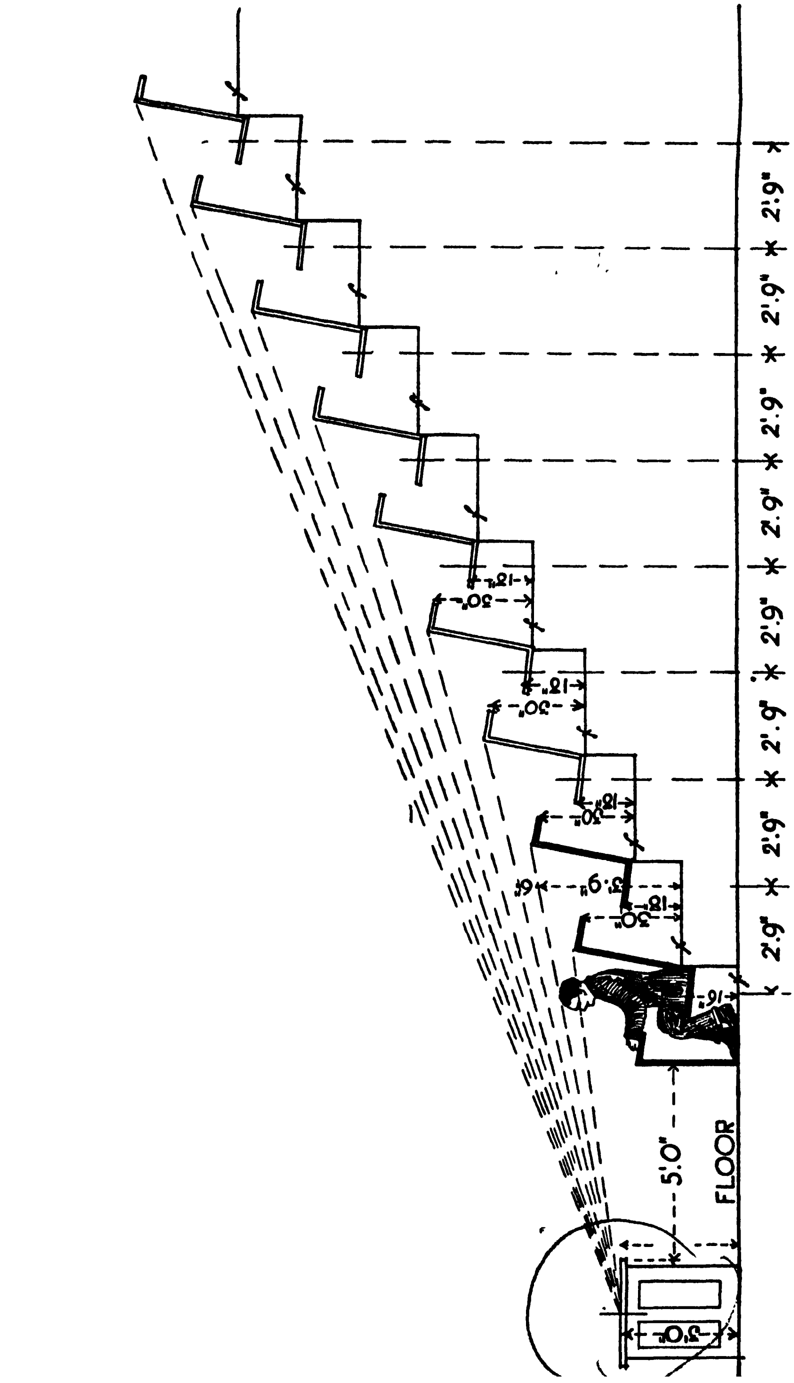


FIG. 30.—Method of Setting Out Raised Seating for a Lecture Theatre.

section through such seating and the constructional lines necessary for its determination.

Preparation Room.—No rules can be laid down for the size of a preparation room. It should be remembered, however, that for advanced work much setting up of delicate apparatus may be done here, hence the area must not be too limited. In a school, space for ample shelving and a good wall bench will usually be sufficient, but for advanced work a large central bench has often to be accommodated in addition. Two doors are usually necessary, one to the lecture theatre and the other to the corridor or possibly laboratory. These should be near one another if possible so that the room does not become a passage. The floor is preferably wood, and so much of the walls are covered by cupboards that if tiles or glazed bricks are used on the walls they are only necessary to a very limited extent. Sometimes this room is used for making up solutions of given strength, when its character will differ somewhat from a room wholly at the disposal of a lecture theatre.

Preparation Room Fittings.—The fittings usually comprise a good centre bench and one or more wall benches fitted below with cupboards, a very large sink with ample services, and a fume cupboard and shelves. The benches do not get the rough usage of a laboratory, hence hardwood tops are not so necessary, but a small area should be incombustible, and if no separate blow-pipe table is provided this should be rather lower than the general height, say 2 ft. 9 ins. No recognized principles appear to exist as to drawers and cupboards, but the former are required in much larger numbers than in the students' benches, and vary in size.

The sink is best kept as a separate fitting, and in a large institution may be about 3 ft. 6 ins. by 1 ft. 6 ins. by 1 ft. deep, enabling a quantity of apparatus to be dealt with at one time. Ample draining boards are of course required, above which, or arranged as a separate rectangular stand, as used in the new organic laboratory at Oxford, wood grids formed by cross pieces about 1 in. square, intersecting at right angles to form openings about 2 ins. square, will be found valuable as drying racks for glass.

The use of a fume cupboard as a hatch to the lecture room has been referred to. In this position the projection of the cupboard should be into the preparation room.

A good idea of the shelving wanted in a room devoted largely to re-

agents (that is, chemicals as contrasted with apparatus) is obtainable from **Fig. 31**, which shows a photograph of the main preparation room in Beckmann's laboratory at Leipzig; the foot rail round the walls is a useful feature, both protecting glass near the floor and forming a ready means of reaching the higher shelves. To raise the floor about 3 ins. at the walls as a platform,

FIG. 31.—Preparation Room, Beckmann's Laboratory, Leipzig.

6 to 9 ins. wide, will be found useful for storage by enabling the floors to be cleaned without fear of breakage of things in this position.

Store Room.—Where only one store is provided the floor is best of asphalt, laid to an outlet if possible, as although the breakage of a winchester of strong sulphuric acid or ether is a rare thing, it is an incident to be reckoned with. Whether such a floor is provided or not a box of sand should be installed in a definite position. Chemicals are kept in bottles or jars, and apparatus consists mostly of light glass, such as flasks and beakers,

some of which may be of considerable size. Porcelain dishes and small materials such as corks, rubber tube, and crucibles require drawers.

Racks for stocks of glass tubes, which may be 6 ft. long and are mostly about $\frac{1}{4}$ in. in diameter, are also required. These may be vertical or horizontal. The former arrangement best shows the lengths, the latter the bore. Possibly a vertical rack in which the tubes stand on hard glass with a mirror below might be contrived with some advantage, to give an indication of length and bore at a glance.

At Bristol University, Prof. Francis uses for the main stock of glass, island cupboards, about 12 ft. by 4 ft. and 7 ft. 6 ins. high, which have sliding doors on both sides, the shelves running right through without a division. With both doors open everything is readily seen and reached. Round the walls the shelving at the floor is protected by a foot rail similar to that shown in **Fig. 31.** To enable stock to be purchased to advantage in large quantities storage space should be ample. Sometimes roof space may be used where economy makes the necessary floor space unattainable elsewhere.

Balance Room.—For elementary work, balances may be often used in the laboratory itself, if placed in good glazed cases, but a special room is desirable and may have merely a glazed screen between it and the laboratory to aid supervision. As no dirty work is done in a balance room the walls need not be finished with glazed ware, and the floor may very suitably be covered with linoleum. A dry still atmosphere and good light, both natural and artificial, are the chief matters of importance. The fittings comprise shelves for the balances, and sometimes cupboards are supplied below for certain special apparatus, though the use of the room for anything not actually required for weighing is to be discouraged. Balance shelves or tables require to be very rigid and are best fixed to substantial walls by brackets. These shelves are usually of slate 1 in. to $1\frac{1}{2}$ ins. thick, but for ordinary purposes substantial wood shelves are very satisfactory. The width need not be more than 15 ins. to 18 ins., hence **T** irons built into the walls form effective supports. A very rigid form of movable shelf, suitable for balances or general use in a research laboratory, consists of a top of slate or wood attached to brackets of wrought iron. A continuous angle iron is built into the wall and engages with an iron plate attached to the back of the shelf (**Fig. 32**). The feet of the brackets are covered with felt and merely press against the wall. The pressure of the hand on the edge of a balance

shelf should not cause disturbance to a swinging balance and the brackets must be strong enough to comply with this condition. For fixed shelves T irons 3 ins. by 3 ins. should be ample. These shelves are often separate for each balance. With solid floors, glazed brick piers are often built at intervals to carry the shelves. Some further comments on vibration and its prevention will be found in the next chapter. It is interesting to note that the late Professor Ramsay's balance, used in many of his classic researches, stood on an ordinary wooden table on a joisted floor, but at the same time it should be mentioned that the latest air-damped French balances are exceedingly sensitive to vibration. **Fig. 33** shows a balance table from Fischer's laboratory in Berlin with cupboards below for special apparatus. These cupboards are not attached to the balance shelf over them.

Each balance requires its individual artificial light, and if electric pendants are fixed at stated intervals, it may happen that more balances are subsequently added, throwing out the lighting. This is got over in the Cambridge Chemical department by placing a brass rod at a suitable height the whole length of the balance shelf, on which the lights are hooked and fed from flexes attached to plugs on the wall behind. They can thus be placed immediately in any convenient position. This rod might, of course, be of hardwood.

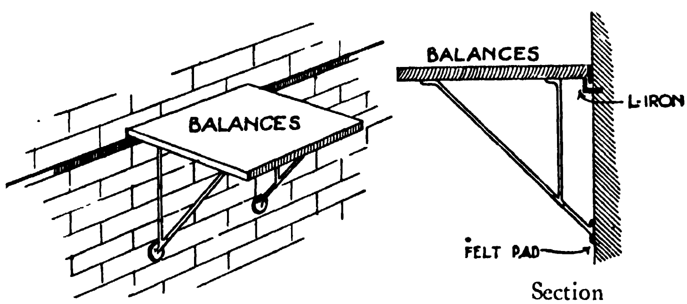


FIG. 32.—Movable Balance Shelves.

Advanced Laboratory Benches.—The general principles which govern the design of an advanced laboratory do not materially differ from those already enunciated, but more bench length per head is necessary, and sometimes more elaborate services. The width of gangways, height and width of benches, provision in the matter of fume cupboards, ovens and side benches, is very similar, but since individual apparatus and cupboard space is greater, less provision is required for public apparatus. The bench length per head should be, if possible, 5 ft. 6 ins., though in a school where this laboratory is not used for much organic or research work the length allowed

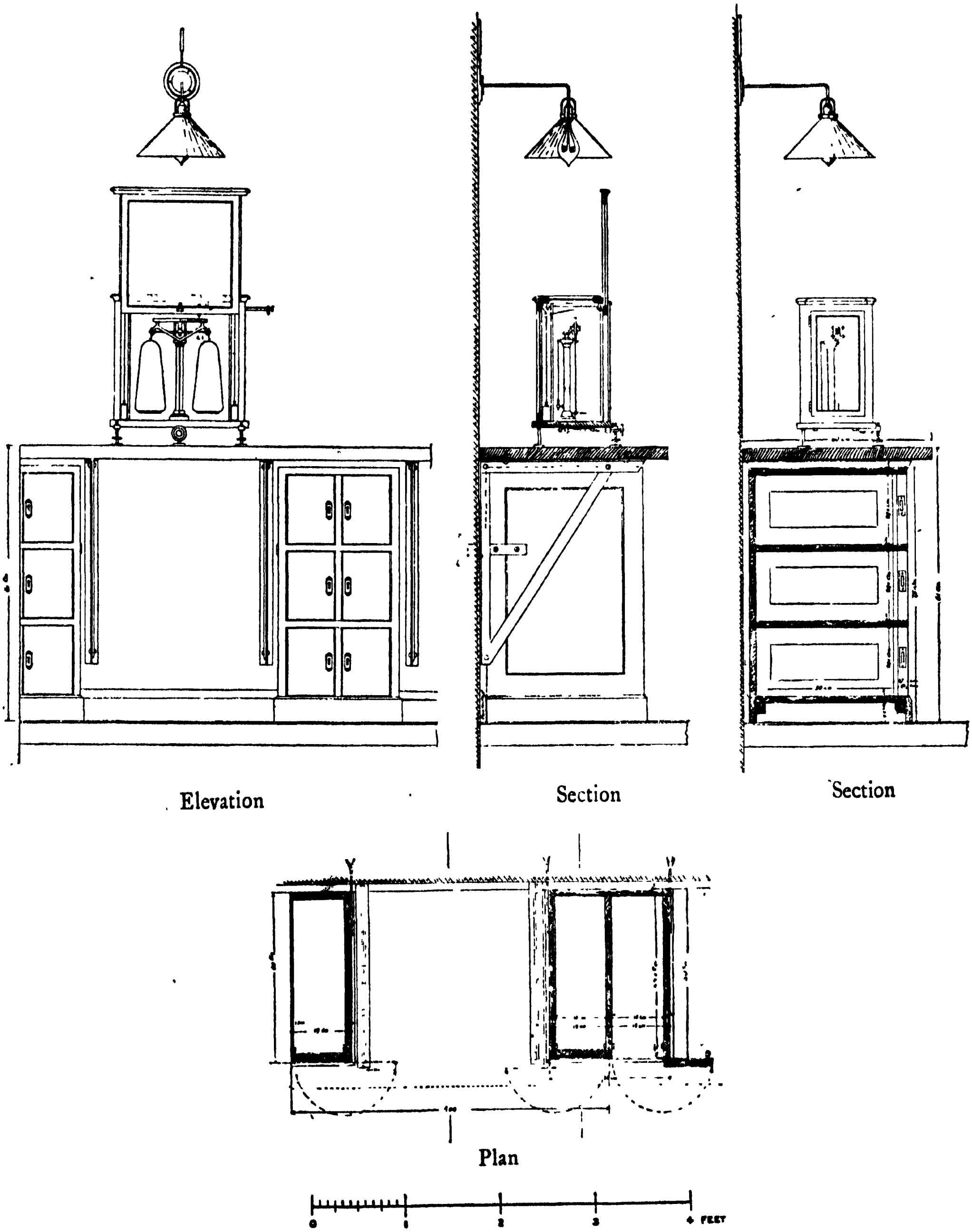


FIG. 33.—Balance Tables, Fischer's Laboratory, Berlin.

is often only 4 ft. After a course in general inorganic chemistry, students usually take up organic work, for which, consequently, an advanced laboratory is chiefly used. This work involves perhaps less variety of small apparatus and reagent bottles, but certainly processes having larger space requirements, such as distillations, extractions, and combustions. Hence, the additional space is a necessity and not merely a convenience.[1] More water jets and wastes are wanted, but less actual washing in sinks is necessary. Hence, the latter may well be at the ends of the benches, and extra water supplies be either over a continuous open lead gutter down the middle of the bench, draining into these sinks, or over drip sinks, or waste holes in lead or glazed ware. Both these methods of disposal are to be seen in recent designs. At the organic laboratory at Oxford, lead channels are used about 4 ins. wide and from $\frac{3}{4}$ to 2 ins. deep. These channels have a fall of about 1 in. in 20 ft., and over them the water nozzles are placed at frequent intervals. At University College, London, each bench for four students has (in addition to the end sinks), in place of lead channels, two drip sinks with supplies; these are $8\frac{1}{2}$ ins. square outside and $5\frac{1}{2}$ ins. cube inside and have movable grids over the wastes (**Fig. 34**). Lastly, draining pegs are most useful on an advanced bench. These are sometimes arranged upon draining boards fixed on either side of the end sinks, sometimes on the ends of the bottle racks. **Fig. 35** shows a sketch of the end of one of the benches in Dr. Perkin's laboratory,[2] above referred to. At Bristol, on certain wall benches, Prof. Francis has draining pegs arranged on the wall in place of reagent shelves. A continuous horizontal wood fillet let into the tiled walls is provided for attaching the pegs, below which is an open lead-covered drain channel, **U** shaped, running along the back of the bench. Another feature found in this laboratory, where red tile topped benches are used to some extent, is a glazed channel at the extreme end of the bench with a flanged lip and waste connection (**Fig. 36**).

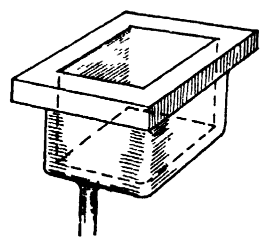


FIG. 34.—Drip Sinks, University College, London.

[1] In the new organic laboratory at University College, London, the double benches for four students are 11 ft. 5 ins. long and 5 ft. wide.

[2] Plans of this laboratory, designed by Mr. Paul Waterhouse, will be found in Chapter VI.

Other Fittings.—The only example known to the writer in this country of a shower rose for the purpose of extinguishing fire on students' clothing is to be found at Bristol. The danger from fire is much greater in organic than in inorganic work on account of the use of ether and other inflammable liquids.

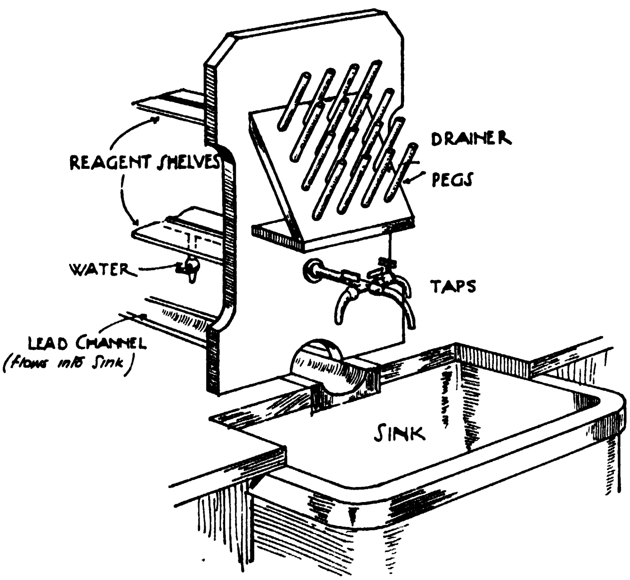


Fig. 35.—End of Students' Bench for General Work in the Organic Chemical Laboratory, Oxford University.

A very large sink is useful for washing and also cooling large flasks; something about 3 ft. by $1\frac{1}{2}$ ft. by 1 ft. deep is often found. At Bristol, a lead-lined sink is used in two compartments, one about 2 ft. by 1 ft. by 1 ft. deep, from which water overflows into a larger sink, no less than 2 ft. deep.

Combustion Room.—By a combustion room is generally understood a room set apart for organic analysis, where a given weight of a compound is burnt under carefully regulated conditions and its products are measured by volume if gaseous, or if not are weighed subsequently in the balance room. Other work such as melting in furnaces, blow-pipe operations and the like, though requiring very similar fittings, is best done in a separate room, because organic com-

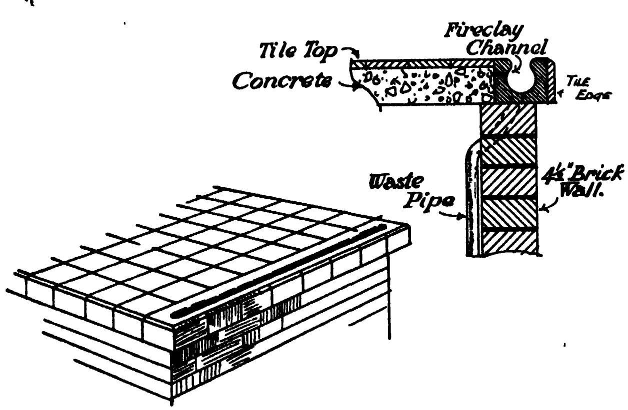


Fig. 36.—Waste Channel to Bench Top, Advanced Chemical Laboratory, Bristol University.

bustions require great care and concentrated attention extending over some hours. The arrangements for organic work consist of benches of concrete with tiled tops, as previously described, or these may be of fine sandstone or even cement-faced concrete. The tops may be carried on brick piers or strong iron brackets. The floor of the room should be cement, tiles, or other incombustible material. Over each bench, which requires an ample gas supply, is a hood connected with a flue to remove combustion products from the furnaces. Near the bench attached to a water supply and waste (preferably in a sink), aspirators—large glass or metal bottles—are provided for attachment to the combustion furnace. The benches are usually against the walls to facilitate draught and water arrangements. A special sink with a well, a few inches square and perhaps 2 ft. deep, in one corner for adjusting the level of water in long vertical tubes, for the eudiometric determination of nitrogen is desirable, and this should be in a good light.

In Fischer's Berlin laboratory the benches are 7 ft. 10 ins. long, 21 ins. wide and 3 ft. 1½ ins. high, and the adjoining sink, which is lead lined, is about 31 ins. by 18 ins. by 5 ins. deep with its top 29½ ins. above the floor. The hoods are of iron, 4 ft. above the bench to the under side with a 2 ft. projection and a steep slope to the wall, the front being hinged to pull back by a chain. At Leipzig the hoods, also adjustable, are covered by asbestic plaster to reduce the radiation which takes place from the bare iron. The arrangements in this laboratory are shown in **Fig. 37.** At University College, London, the hoods for combustion operations generally are made of 2 ins. by 2 ins. T irons built into the walls about 3 ft. apart, connected in front by a 2½ ins. by ⅛ in. iron strip, a light frame 10 ins. deep forming a vertical curtain in front. The whole is filled in with "uralite" (cement and asbestos sheeting). The projection from the wall is 2 ft. 7 ins. The benches are of tiles on concrete supported by a steel frame and braced steel legs.

Dispensary.—In a large building, a room through which all apparatus and chemicals are issued and to which loaned apparatus is returned, is very necessary, as only by some proper system, resembling that of a sales department, can any check be kept upon these materials, which form a large item in annual expenditure. Such a room may be called a dispensary. Materials are drafted into this room from the store rooms, which should be as near as is feasible. Further, many of the stock solutions are often made up here for

the students' requirements. In addition to shelves, cupboards, and drawers, a fume cupboard is required for filling acid bottles, and a counter and flap for handing out materials by the man in charge, who attends at certain specified hours. If solutions are made up, a proper bench fitted with a sink, water, and gas is further required, but in any event a sink will be wanted. Many solutions are kept in large glass aspirators with taps, and these should stand

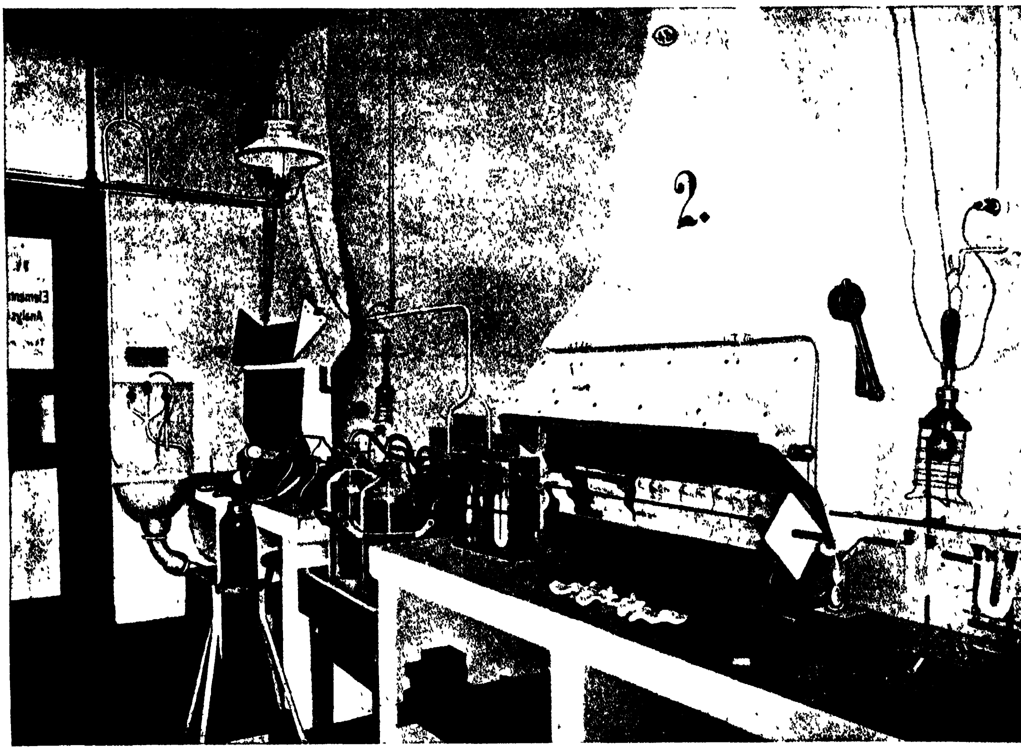


FIG. 37.—Combustion Bench, Leipzig.

together on a shelf, the taps being over a glazed channel with a waste pipe attached. Such an arrangement is used in the dispensary of the organic laboratory at Oxford. Fig. 38 shows a three-tier stand of this kind, used in the organic laboratory itself, at University College, London. Dispensaries sometimes find a place actually in laboratories as small enclosures, but these are chiefly for providing for the special needs of problems set to the junior worker and not for the issue of general stock. These enclosures require shelves, a few cupboards, and drawers, and a small bench with a sink, and

gas and water. It is generally desirable to be able to lock up such enclosures.

Research Rooms.—Researches differ so much in character that no rules for fittings are possible. Such work may be carried on in a large laboratory fitted like an advanced laboratory, with about twice such laboratory's run of bench allotted to each student, or may be conducted in private rooms devoted only to one or two workers. In the latter case as much free space should be given as possible. A good fume cupboard and combustion

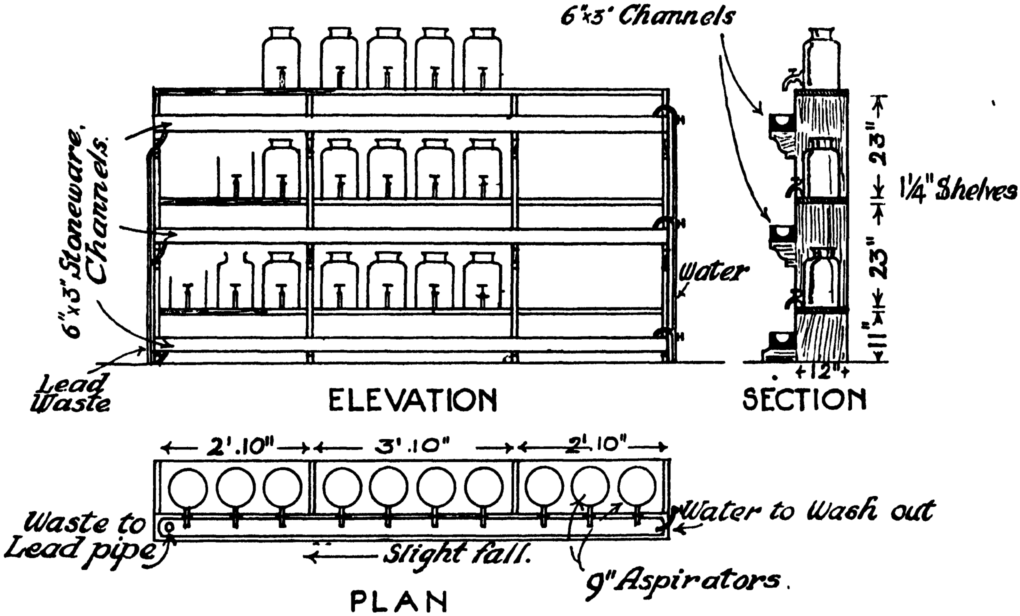


FIG. 38.—Aspirator Stand for Stock and Volumetric Solutions, University College, London.

bench and a large sink are necessarily fixtures, but an ordinary working bench may not be wanted. The scheme which is probably most satisfactory, consists of supplying a teak shelf about 9 ins. wide on one of the walls with water, gas, steam, and electric supplies, drip sinks, and wastes. A few plain tables the same height as the shelf are provided, and these are moved up to the wall for the services, and arranged in any form which the worker finds most convenient. Very often a considerable piece of joinery is required to be made for some special research, hence the centre of the room should be as free from fixtures as possible.

Dark Rooms.—Dark rooms are used both for spectroscope and polari-

meter work. Dark blinds (more fully discussed in the next chapter) and provision for good ventilation are essential in these rooms. A sink, draining board, and bench are often installed so that photographic work can be undertaken. The room should have one or two small loose tables, and a small solid table with incombustible top for the spectroscope, the lamp of which is sometimes provided with a little hood and draught flue. The walls should be of a dull tint, and linoleum forms a suitable floor covering.

Physical-chemical Laboratory.—In recent years very great developments in the field of chemistry where it touches physics have been apparent. The work in this department comprises the study of the effects of heat, light, and electricity upon chemical reactions, and does not involve a large amount of small apparatus and reagents. A solid floor finished with blocks or boards is suitable for this work. The necessary fittings are of two kinds, an ordinary working bench with but a limited supply of sinks and bottle racks, and benches of incombustible material, specially arranged for large apparatus at different levels, and liberally supplied with gas and water, which services often have to be kept in use continuously day and night. It is usually desirable, as in a research laboratory, to keep as much floor space as possible free for any special work, and students require as much bench space as for research purposes.

Sometimes the students work seated, in which cases the ordinary benches may be only 2 ft. 8 ins. or 2 ft. 9 ins. high. Occasionally a heavy incombustible shelf is placed over the benches, supported by machined columns, which admit of its adjustment to various heights. One of the benches again may have a raised bead in front for mercury experiments. The other class of bench alluded to is generally made of concrete slabs about 3 ins. thick, covered with red tiles, and supported on glazed brick piers or iron supports. Those used at University College, London, are shown in **Fig. 39,** and are 2 ft. 6 ins. wide, and alternately 3 ft. and 18 ins. high, in lengths of 5 ft. to 6 ft., the lower slabs being supported on steel channels and legs, built into wall and floor. Gas and water are supplied at the higher level.

Electro-chemical Laboratory.—Though electro-chemistry is strictly a branch of physical chemistry, it embraces so large a field, covering all electrolytic work, that it is generally classed as a distinct subject. The fittings above described are suitable for such a laboratory, but a great deal of electric wiring for experimental purposes (further alluded to in Chapter V)

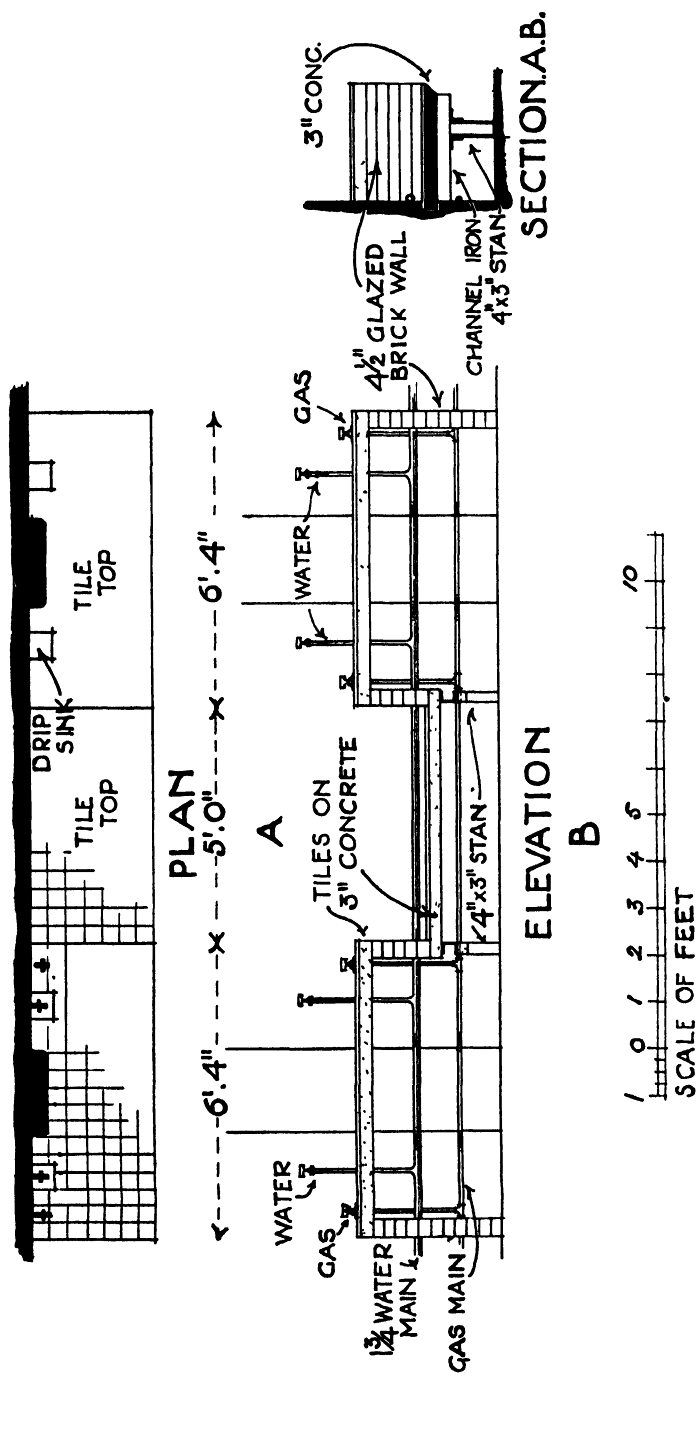


Fig. 39.—Physical Chemistry Laboratory Benches.

is necessary. **Fig. 40** shows a photograph of Prof. Lewis's general laboratory at the institute devoted to this subject at Liverpool University[1]. The double benches (not that in the foreground) are 12 ft. by 5 ft. and 3 ft. high.

Sulphuretted Hydrogen Room.—Where much sulphuretted hydrogen

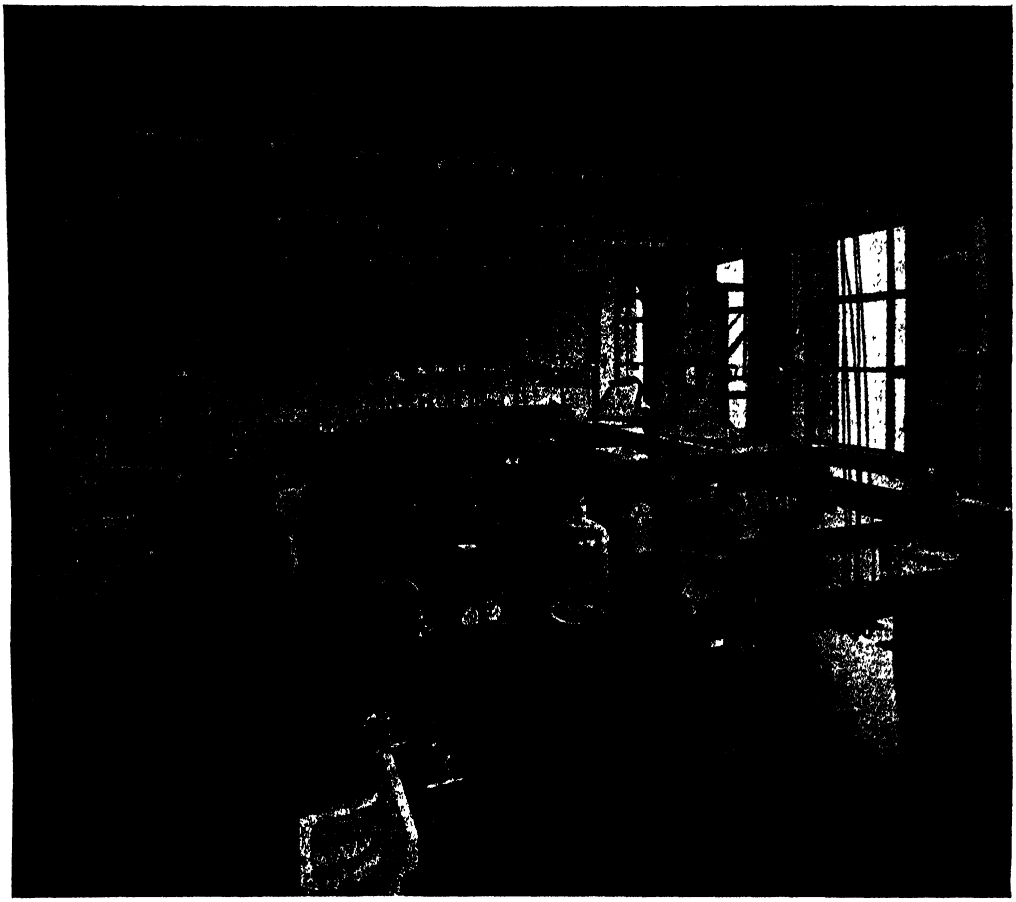


FIG. 40.—Electro-Chemical Laboratory, Liverpool University.

(which is not only evil smelling, but poisonous and inflammable) is used, it is desirable to have a small annexe to the laboratory devoted to it, though in most schemes one or two fume cupboards are merely set apart for it in the laboratory itself. Such an annexe should be as open to the air as protection from wind and weather will permit, and as operations are transient,

[1] For plans see Chap. VI.

need not be heated. The room contains one or more fume cupboards approached by suitable gangways, one cupboard being usually devoted to the apparatus for making the gas, which is laid on in glass or lead tubes to various points in the others. The corrosive effects of this gas on metal are so great that every effort must be taken to keep gas and water fittings outside the cupboards, and to reduce metal work in the annexe to a minimum. The floor of this room may be suitably of asphalt. To prevent the constant small evolution of the gas from the water surface, necessarily exposed in the supply apparatus, this surface may be covered with paraffin oil. At Leipzig the gas is made and stored in a regular gasometer in the basement, and laid on to the laboratories, but this arrangement is very unusual.

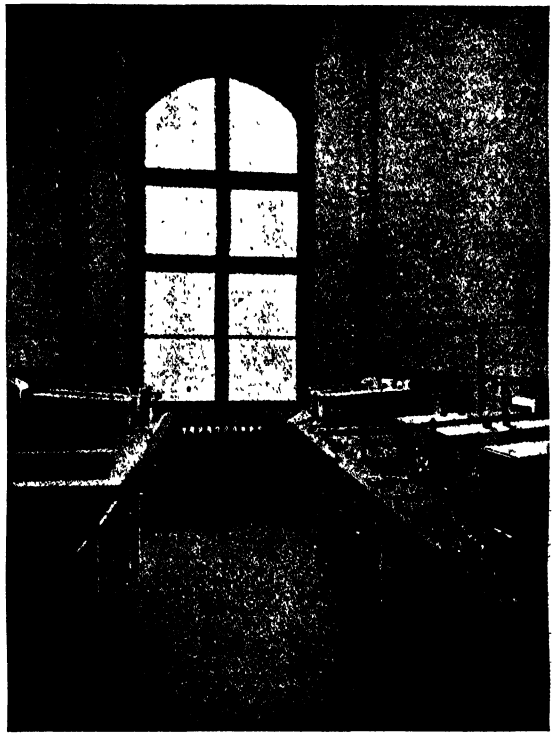
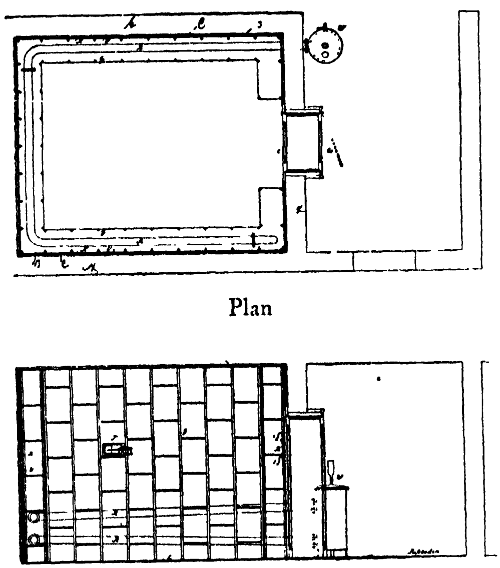


Fig. 41.—Closed Tube Room, Chemical Institute, Berlin.

Closed Tube Room.—In a large department a small room for organic analysis by decomposition under pressure is desirable owing to liability to explosion. This decomposition is effected in glass tubes some 18 ins. long and 2 ins. in diameter which are heated by gas in small cylindrical portable ovens which stand on a bench. The gas supply necessary is quite small, as these tubes are only heated slightly. This operation may take place in the combustion room or in the organic laboratory itself, provided effectual protection is arranged in the form of a strong iron case or cupboard. Naturally everything in such a room or area should be of incombustible materials, the benches of stone or concrete and the floor in cement or tiled. **Fig. 41** shows this room with a series of the ovens on the benches in Fischer's laboratory in Berlin.

Constant Temperature Room.—For constant temperature work it is often considered sufficient to provide in the basement in the interior of the building, or on an aspect subject to little change of temperature, a room eight or ten feet square, with double walls with a hollow space between them and a thick non-conducting door, or two doors so that one can be closed before the second is opened. Such a room is valuable for crystallizations and the like. When, however, incubations are required the temperature must not only be constant but capable of control at will, which is a less simple matter. **Fig.** 42 shows the room for this latter purpose in Fischer's laboratory, Berlin. The walls are double, with an air space between, and upon the internal walls, floor, and ceiling, wood strips are fixed to which are attached sheets of vulcanite to form a continuous surface; on this, to walls and ceiling, sheet copper is laid, to aid in a uniform distribution of temperature, the floor being covered by linoleum. Racks for culture vessels, which can be pulled out, are arranged round the room, which is heated by hot water pipes attached to a boiler heated by gas in an adjoining room. A thermostat regulates the gas and thus the temperature of the boiler. The gas consumption is not more than would be required for a laboratory oven. The room has a special vent pipe controlled by a damper.



Plan

Section

FIG. 42.—Constant Temperature Room, Chemical Institute, Berlin.

Metallurgical Furnace Room.—As already stated, metallurgy is a subject bordering on technical chemistry, and, therefore, may not be represented in an institution of considerable magnitude. Most University schemes, however, include such a department. Two or more rooms are desirable, a furnace room and a laboratory, and often a separate balance room, and, of

course, a complete suite of rooms, as for other branches of chemical work, may be necessary in certain instances. In the furnace room metals are melted in furnaces operated by coke, gas, or electric power, and the fittings should be of an incombustible nature. Two main classes of furnaces are required, known as "wind" and "muffle" furnaces; the former are generally operated by coke burning under the natural draught of a tall chimney, hence the desirability of placing this room at the bottom of the building of ordinary height to obtain an efficient length of flue. Very high temperatures have to be attained in these furnaces, and perhaps 50 ft. may be taken as an average length of vertical flue necessary.[1] The usual type of wind furnace cannot be supplied by an apparatus maker but must be erected to design by a builder, and so few illustrations are available that a working drawing of a single furnace recently erected by the author for Westminster School is shown in **Fig. 43.** Inspection of more recent examples does not suggest that the general design of these furnaces has been substantially modified.[2] A wind furnace usually consists of a 9 in. by 9 in. opening, surrounded by 9 ins. of brickwork and standing 2 ft. 9 ins. high. At a depth of about 1 ft. 4 ins. a set of heavy wrought-iron movable bars (club-headed to keep them distanced) are supported by two wrought-iron bars built in below. The whole of the interior must be in firebrick with thin fireclay joints. The flue is at the side or back of the furnace at the top. In the example shown the flue had to be carried horizontally cut into the wall to an existing flue in another part of the room, but this would be unnecessary if flue and furnace were designed together. The furnace has a cast-iron top (wrought iron is unsuitable, as it warps), perforated for the full opening (9 ins. by 9 ins.) which is covered by two loose fireclay slabs of different size bound with iron straps, and these are handled with tongs. At the floor level is a furnace door with damper by which the draught can be regulated. A damper is also provided in the flue (see section EE.). The elongation of the table top shown in the elevation is merely for the purpose of carrying the muffle furnace, which (as is usual) is heated by gas and also requires a flue, generally arranged with an opening in the wall, to which a small hood is attached to receive the gases from an open wrought-iron flue pipe about 3 ft. long, placed on the top of the muffle.

[1] The wind furnace flue at Birmingham University is 70 ft. in height.
[2] Detached iron furnaces lined with fire-brick are however sometimes employed.

Where several wind furnaces are wanted they are all connected to one main chimney shaft, placed as centrally as possible, by branch flues sloping up at an angle which should be not less than 30 degrees even for those most distant from the shaft. Dampers in each flue are very desirable

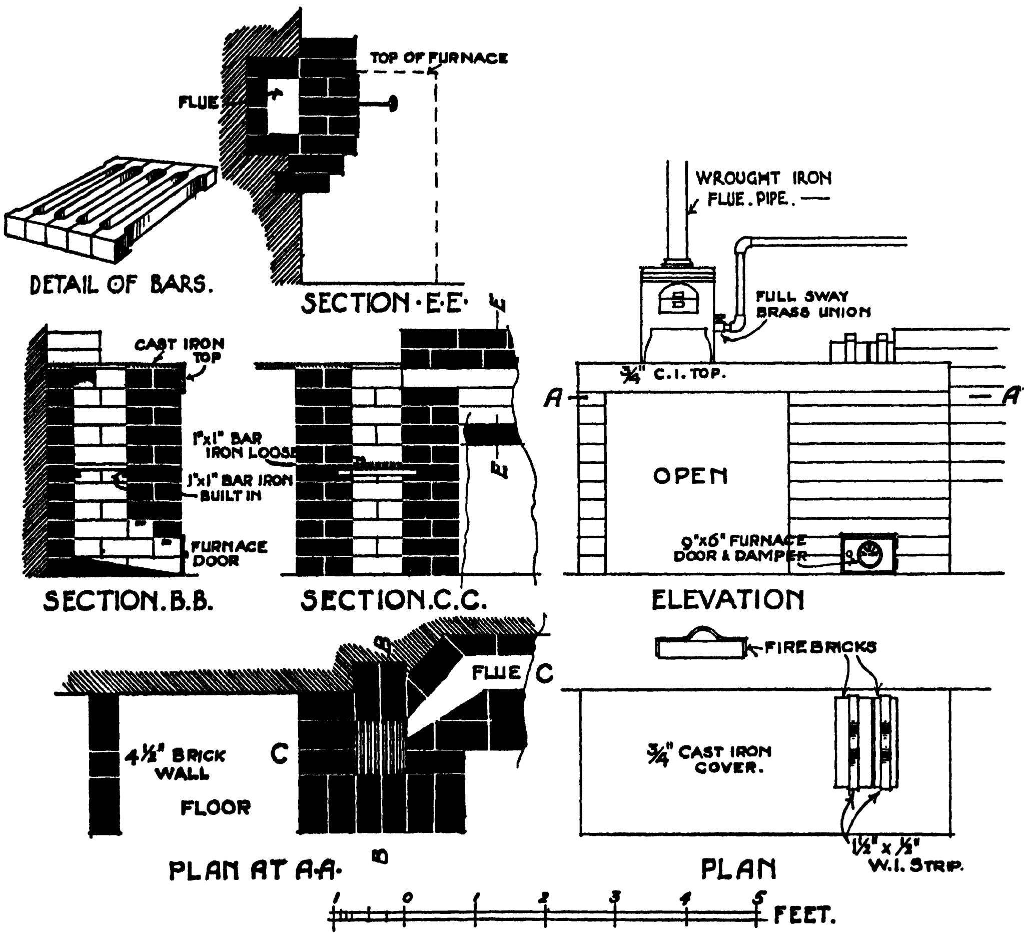


Fig. 43.—Metallurgical Furnace Details.

to give means for equalizing the draught when several furnaces are in use together.

Fig. 44 shows a furnace room in Fischer's laboratory. On the left is a fan and motor for giving a forced draught; to the right a wind furnace of a detached type made of fireclay blocks, cased in iron externally; and in the corner on the right a somewhat similar but smaller furnace operated by gas.

Other fittings required in the furnace room are one or two strong benches for cutting metal and using mortars, and for a small milling machine; and perhaps one or more pieces of tree trunk about 2 ft. 6 ins. long and with iron bands at the top for use as blocks for hammering and the like. Bins or retaining boards for coke and possibly also for ores, used in experimental work, will also be necessary.

Metallurgical Laboratory.—The necessity for a laboratory for metal-

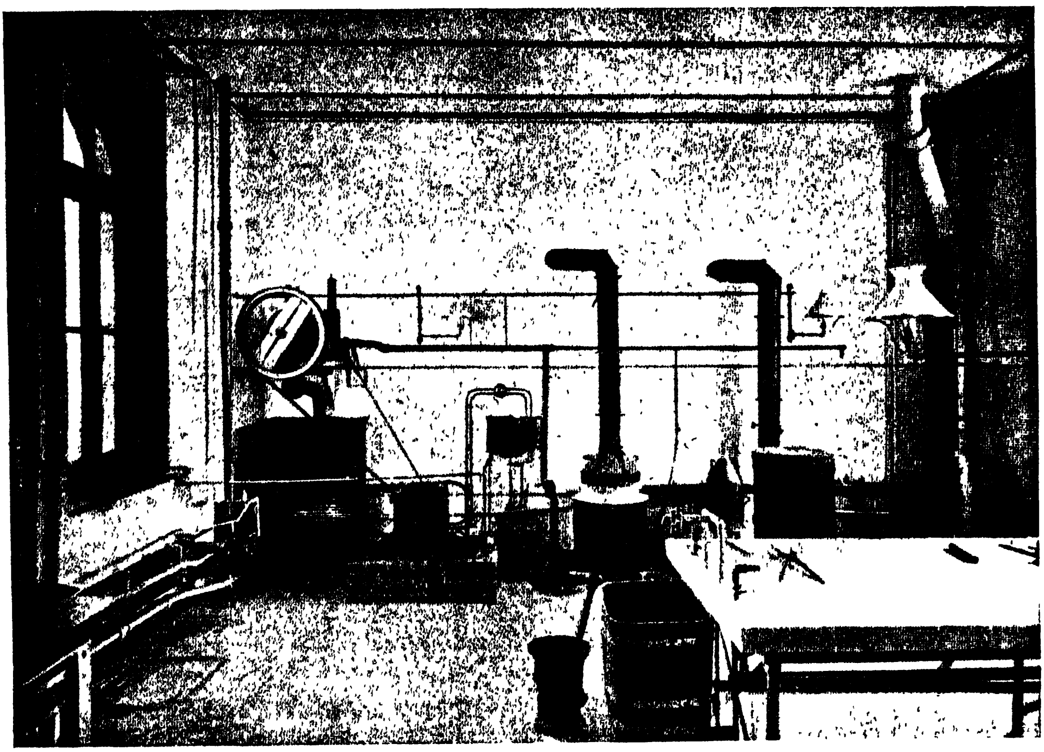


Fig. 44.—Metallurgical Laboratory, Chemical Institute, Berlin.

lurgy will depend largely on the magnitude of the department and its opportunities of utilizing other laboratories which the institution may possess. Much important work has recently been done on the microstructure of metals, and for this work microscope benches and photographic facilities are necessary. Etching with acids and other chemicals is also required. The working benches are of ordinary construction, those for microscope work being lower (see Chapter IV). A fume cupboard is required, and a bench

of incombustible material, as described for physical chemistry (page 62), will sometimes prove valuable. If balance cases have to be designed, particulars should be ascertained, since one or more assay balances are often of much greater size than those in use for ordinary work.

Liquid Air Room.—Liquid air is produced on a small scale in all chemical departments of any magnitude, and a basement room about 12 ft. long by 8 ft. or even narrower is sufficient for the purpose, and should be under the sole control of those responsible for the plant. Several types of plant exist, but if the room has a solid floor, which should be finished in cement, no special foundations are necessary. The dimensions of the room suggested assume that power is available from some external source, and this is usually electric power supplied to a motor of about 5 h.p., which should be placed on a rail bed for facility in adjusting belting. The space occupied by such a motor will be some 3 ft. by 2 ft. 6 ins. by 2 ft. 6 ins. high. This motor drives (usually by belting) an air compressor pump, the valves of which are lubricated with distilled water. The Whitehead double action pump, often used, is of a horizontal type, with a compression coil at each end, immersed in running water. For the power suggested it is about 5 ft. long, 2 ft. across, and 2 ft. high. Before entering the pump, the air is drawn through a large drum some 18 ins. in diameter and 2 ft. 6 ins. to 3 ft. high, filled with lime to remove carbonic acid gas, always present in the atmosphere, after which it enters the pump and is compressed to about 180 atmospheres (850 lb. to the square inch). It then passes into two cylinders a few inches in diameter and 2 ft. to 3 ft. long, in which the last traces of water and carbonic acid are removed, and from these into the liquefier, also a cylinder about 2 ft. long and some 8 ins. in diameter, which is filled with coils of small piping, which convey the air under pressure, and round these coils part of the air is also released from pressure and cools on expansion sufficiently to liquefy the air in the coils which is drawn off into suitably jacketed vessels at the bottom of this liquefier. Liquid air can be obtained after running the pump for about 20 minutes, and with such a plant as described, is produced at the average rate of a litre ($1\frac{3}{4}$ pints) an hour. If 3 ft. to 4 ft. clear be given between the motor and pump sufficient room will be allowed for the belting, and as the rest of the apparatus is stationary it can be placed in any convenient position. **Fig. 45** shows the plant in use at University College, London. The motor, not shown (previously used

for other purposes), is larger than necessary ($12\frac{1}{2}$ h.p.). The pump is a Whitehead compressor, and the producer a Hampson liquefier, from which the air expanding round the coils is returned to the compressor, thus decreasing the amount to be purified.

Acid and Special Stores.—In large institutions a special room for acids

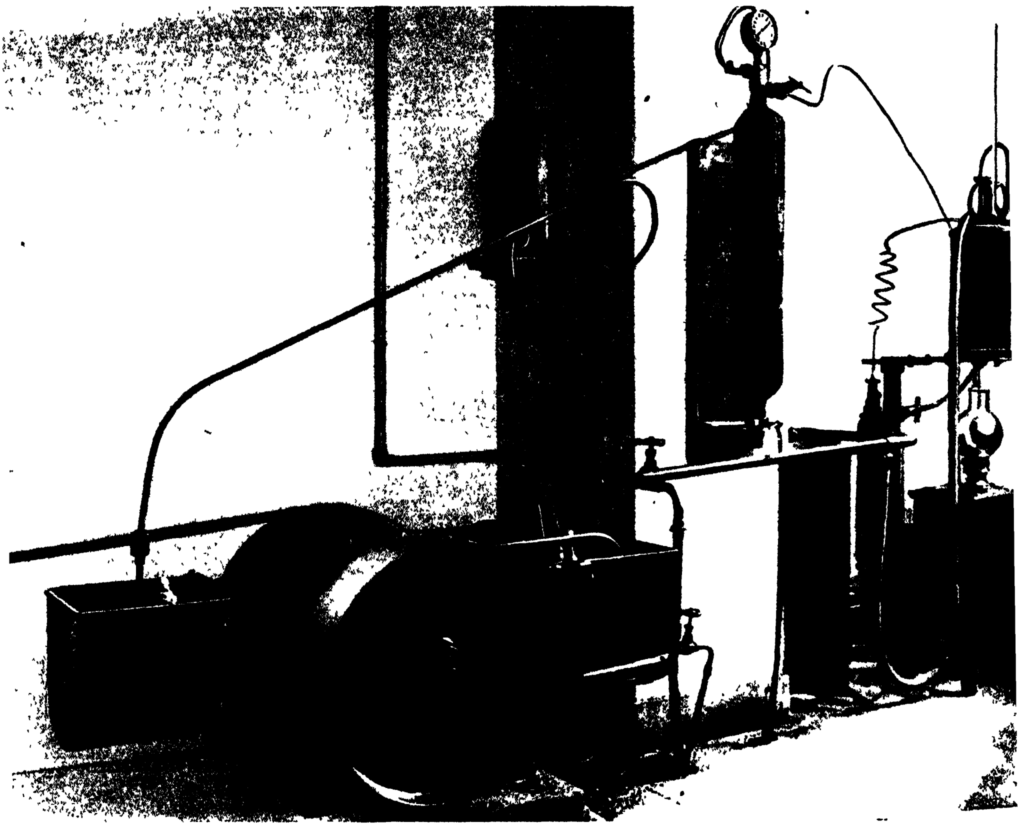


Fig. 45.—Liquid Air Plant, University College, London.

is desirable, with a solid floor covered with asphalt and laid to fall to a special drain or catch pit not connected with the general drainage system, as a provision in case of breakage. Strong acids are also diluted with water in this room, and carboys—6 gallon glass vessels in wicker cases supported on an iron frame on which they can be safely tilted—are emptied into smaller bottles. Plenty of strong shelving to hold Winchester quart bottles, which are about 14 ins. high and $4\frac{3}{4}$ ins. in diameter, a place for funnels and

similar apparatus, and a sink and water supply are necessary. Where any quantity of ether, alcohol, benzene, and like inflammable liquids are used, a special store, devoid of combustible materials and with an iron door external to the building, is desirable. The windows of such a store should have iron shutters operated externally, and a shower rose with both internal and external tap should be supplied in the ceiling. The floor may be in cement or asphalt, and should be laid to fall as for acids.

A special place under control, such as a cupboard in a wall with slate shelves and an iron door, is sometimes used in store rooms for keeping phosphorus, sodium, and other dangerous chemicals, while a small locked cupboard of ordinary type may be desirable for certain violent poisons, such as alkaloids.

CHAPTER III.

THE REQUIREMENTS OF PHYSICS.

NATURE of Work.—Physics is generally studied in an elementary way with or before chemistry. Essentially a science of measurement which deals with the effects of various forms of energy on materials as contrasted with chemistry, which is concerned with the composition of materials, experimental physics is almost wholly quantitative. The fittings of a physics laboratory are less elaborate than those of a chemical laboratory, but the apparatus required is more elaborate. While the branches of physics are more easily defined than those of chemistry, the actual separation of the work in this subject under specific rooms is difficult, because the general similarity of the fittings is greater than in the case of chemistry. The branches of physics are mensuration, mechanics, heat, optics, acoustics, and magnetism and electricity. The first is really applied mathematics and deals with simple measurements, the second merges in a practical direction into the actual uses of machinery, while the last is often extended into the technical applications of electricity which form such an important factor in modern life. This is not the place in which to discuss educational programmes, but in most schools possessing laboratories and workshops very little advantage appears to be taken of opportunities which exist for connecting the theory and principles taught in the former with the practical training obtained in the latter.

In the case of a small scheme with different subjects in one building, the physics department generally occupies the ground floor, but as such a department of any magnitude must involve several floors, this cannot be regarded as essential. The fumes and smells of chemistry suggest an upper floor, but the drainage and stock requirements make a ground floor decidedly simpler, and for average work in a well-constructed building there is no reason against the reversal of the usual floors for these subjects if this appears advantageous.

Vibration.—One of the first considerations of the designer of a physical department is probably the question of vibration, and as much misconception appears to exist on this subject, it may be dealt with generally here. For advanced work in certain departments of physics, freedom from vibration is so essential that the whole construction of the building and even its site may be modified by this necessity, and an example will be found in Chapter VI illustrative of the great amount of care expended upon this problem. In the same manner the magnetic disturbances caused by electric currents used in commercial undertakings quite external to the building may in certain delicate researches have a most detrimental influence, but having said this it may be added that for the work undertaken by the average student, even of university standing, no elaborate precautions are required. A well-built structure in ordinary surroundings will provide upon its main walls, and particularly near the intersection of cross walls, sufficient stability for ordinary mirror galvanometer work if these instruments are supported on masonry corbles, and needless expense is often incurred by carrying down to considerable depths, isolated brick piers through perhaps more than one storey for this purpose. If such piers are decided upon, and this decision must of course rest with the teaching staff, every effort should be made to remove or combat any surrounding causes of vibration which exist ; the installation of moving machinery may easily negative very elaborate efforts to produce quiescence, and in this connection anything in the nature of an internal combustion engine is much more detrimental than a running machine. Where movement beyond control exists near the building, as for example, on an island site surrounded by heavy traffic, or near moving machinery, the inevitable vibration must be absorbed by a bed of confined sand or similar device. A very severe test for vibration is the steadiness of a beam of light reflected from a mercury surface, and this forms a simple means of recording the relative effect of possible disturbing causes on a site or in an existing building proposed to be used for physical experiments, but a great deal of delicate physical work can be done where a perfectly still mercury surface is not obtainable.

List of Rooms.—As explained above, it is difficult to give a satisfactory list of rooms for physics but this may be attempted ; and on the lines of the last chapter, those marked (1) may be regarded as the minimum and with those marked (2) will form a desirable scheme for a large secondary school.

1. General laboratory.
1. Lecture room.
1. Preparation room.
2. Workshop.
2. Optical room.
2. Advanced laboratory
2. Store room.
Balance room.
Photographic room.
Mechanics' laboratory.
Heat laboratory.
Electrical laboratory.
Switchboard room.
Accumulator room.
Research laboratories.
Library.
Staff rooms.

Uses and Relation of the Rooms.—The uses and planning of these rooms, as far as their relations are concerned, will now be discussed.

If more than one laboratory exists a general laboratory will be usually devoted to mensuration, elementary mechanics, and heat, but quite possibly the whole range of subjects for a first year course will be conducted therein. A good deal of small apparatus, in addition to larger pieces suitable for glazed cupboards, is required, and means for darkening the room is necessary.

The lecture room resembles in its design and relations to the laboratory that described for chemistry.

The preparation room, conveniently placed between the above in a small scheme, requires considerable space for the often bulky apparatus required for demonstration, and though a fume cupboard is not necessary connection with the lecture room through a similar medium is desirable.

Store rooms for physics should be arranged for the safe keeping of much delicate apparatus which may be damaged by damp and dust. These rooms, therefore, demand a somewhat better situation and certainly better fittings than those for chemistry, but the consumption of stock is much smaller.

Balance rooms, which should adjoin the laboratories, are not so necessary in a physical as in a chemical department, and for elementary work are often dispensed with, space in the laboratory being found for balances. When provided, these rooms resemble those for chemistry.

Workshop repairs to physical instruments are frequent, and a capable assistant can often make a great deal of simple apparatus. Such a shop need not be large, but should be in close touch with the laboratories.

Optical rooms were formerly held necessary even in very small schemes, but optics is best studied in the general laboratory provided with efficient

blinds. For certain photometric experiments, however, a special room is very desirable, owing to the fixed apparatus required. When provided, this room usually adjoins a laboratory and often has no separate approach.

Advanced laboratories do not materially differ from elementary rooms in their fittings, and are also used for a large range of work, but more space per head is necessary and usually more extensive supply services. Accumulators special to the laboratory are, moreover, generally required to enable large low voltage currents to be obtained, and, owing to the acid they project into the atmosphere, need a special room or, if few, a suitable enclosure, usually on the ground level.

To turn to the individual branches of physics, mechanics in its more applied stages involves the study of machine principles on a working scale, and here tests on materials are usually made. Occasionally, special foundations for heavy loads have to be dealt with in this department. Electrical work forms so important a part of physics that a special room is often devoted to it ; indeed, where commercial electric machines are installed two or more rooms are necessary, as running tests on motors with various loads and the like, are not suitable for a room in which delicate experiments are in progress. The room for the former purpose resembles a workshop, and for the latter is merely an advanced laboratory, and if this can be near the lecture room some advantages in connection with movement of delicate apparatus will often be obtained. Switchboards are desirably placed in special rooms in schemes of any size, in order to be under suitable control ; here also rotary or stationary transformers may find a home. To reduce the cost of wiring, the main board should be near the accumulator room.

The General Laboratory.—Owing to the absence of corrosive fumes and the small amount of water required in a physical laboratory the provision in the matter of special surfaces is not so important as it is for chemical work. A large part of the wall surface is usually covered by shelves and cupboards and the walls may therefore be merely plastered. The floor is usually of wood blocks, but if care is taken in the matter of the occasional use of alkaline solutions there is no reason why a really good linoleum should not be used, and in a new building this could be laid on cement, not only saving the expense of boarding, but removing any possible trouble due to the decay of such boards under this covering. An oblong room, well lighted

from both sides if possible, is most desirable for a physical as for a chemical laboratory.

Fittings.—The fittings usually comprise working benches, cupboards for apparatus, one or more large sinks, drawers of various sizes, balance shelves, and sometimes wall and ceiling fixtures for attaching apparatus. If no demonstration table is required, at least a blackboard should be placed in some conspicuous position. Cupboards and balances are generally placed on walls, and the demonstration table (if any) at one end of the room. Working benches should be in the middle of the room and are preferably ordinary, strongly built tables, approachable on all sides, designed for two or four students. In many laboratories, however, continuous long tables are found and are in favour. They are more economical of space, but facility for getting to apparatus from all sides has many advantages. In the case of long tables 4 ft. or at least 3 ft. 6 ins., as for chemistry, should be given to each student, and if, as is usual, work is done on both sides, that is, they are double benches, their width should be 4 ft. Rather more than half this width is necessary for single benches. The necessary gangways are influenced somewhat by the style of bench adopted. If single tables with passage ways between their ends are used the space between one table and the next may be rather less than if continuous benches are adopted, since in the former case the same necessity for the demonstrator to pass between two rows of students working back to back will not exist. 2 ft. 6 ins. to 5 ft. 6 ins. may be taken as the limits, the former for a gangway not containing students' places or down which no traffic passes, the latter for a long pair of benches with students back to back.

The Board of Education (England) gives 30 square feet per head as the allowance over the whole room for a physical, as for a chemical laboratory, but it will be found rather difficult to arrange an adequately spaced and fitted room on this basis if small tables are used.

Through the kindness of Mr. A. Kelly of the Irish Education Board and of the institutions in question, three plans of physical laboratories obtained by this Board in preparing a report upon experimental science relative to education in Ireland, are here given.

Fig. 46 shows a plan of the Dundee High School laboratory, which is also used for demonstrations, and contains desks for 18 students. The table with slate at each end behind these desks, is used for work in which freedom

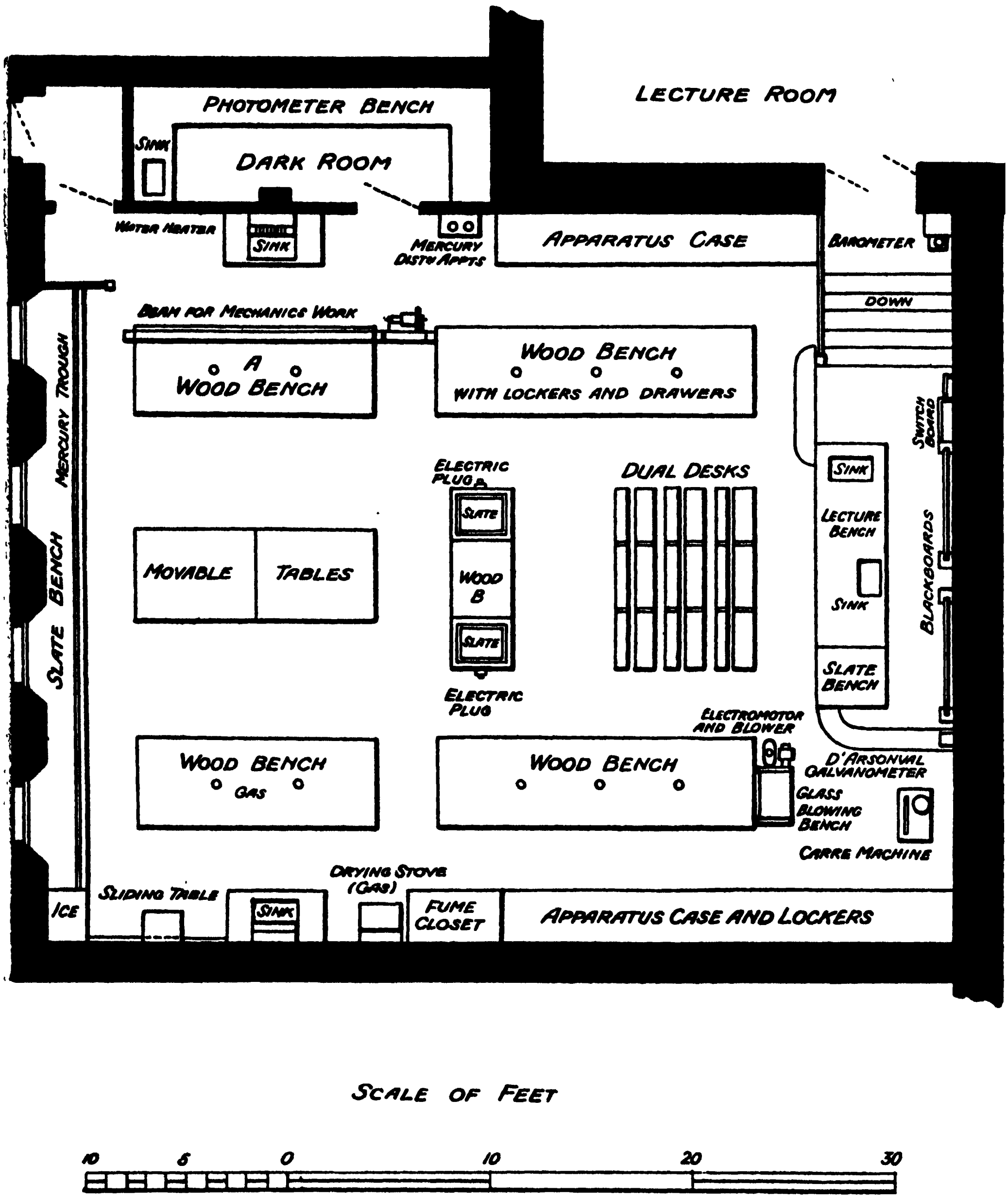


FIG. 46.—Physical Laboratory, Dundee High School.

from vibration is essential, and the movable tables near the window are designed to admit of a clear floor space for any special experiment.

Fig. 47 shows the laboratory at Addey and Stanhope School, Deptford, in which long benches are adopted. In this room a few students also study physiology. The glass-blowing table resembles the blow-pipe table described in the last chapter. A special table for experiments with mercury is provided.

Fig. 48 shows the arrangement of the Heriot-Watt College, Edinburgh. Here again single tables are used, the three square tables in the middle of the room being for apparatus affected by vibration.

Fig. 49 gives a standard arrangement of laboratory fittings adopted by the School-house Department, Boston, the plan being

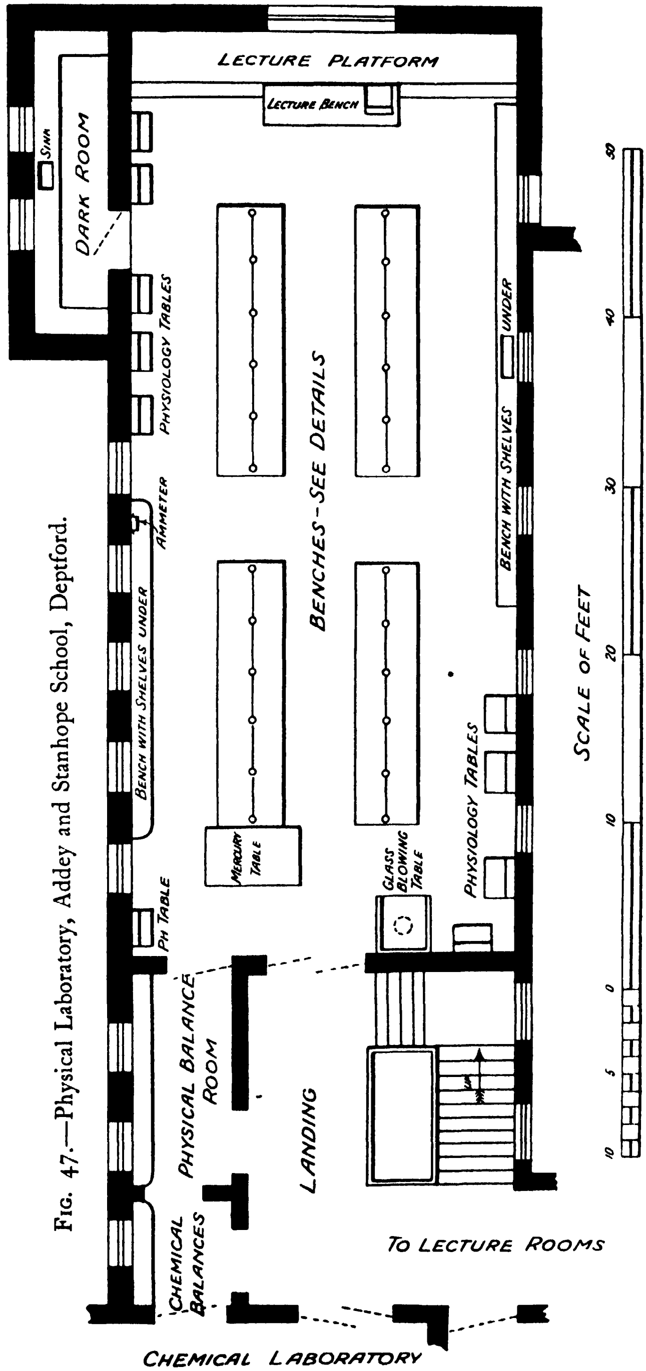


FIG. 47.—Physical Laboratory, Addey and Stanhope School, Deptford.

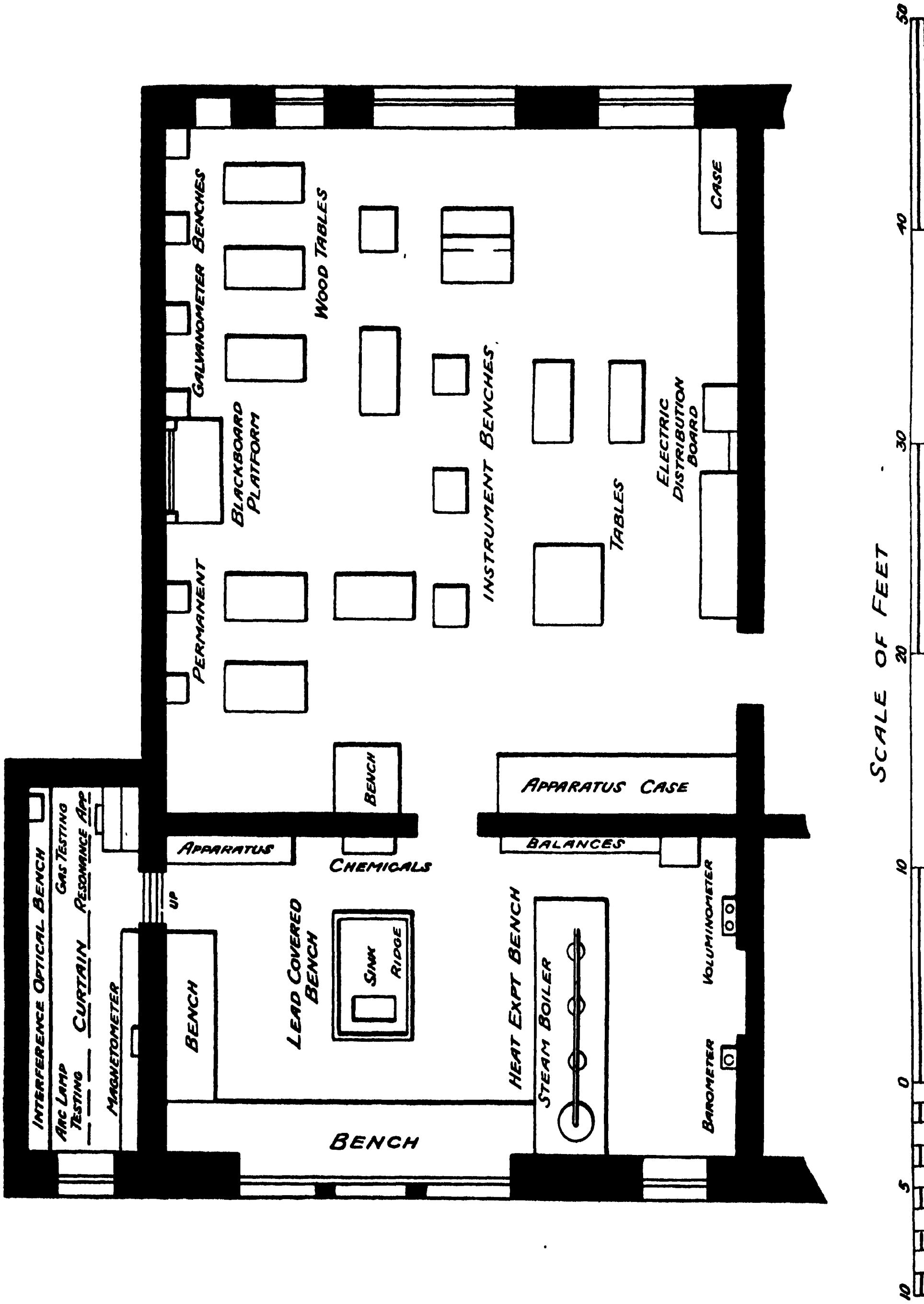


Fig. 48.—Physical Laboratory, Heriot-Watt College, Edinburgh.

taken from the report of this Department for 1916. A detail of the benches shown, is given on page 85.

From the above plans, introduced here as more concerned with fittings than departmental design, the laying out of the benches suitable for a physical laboratory may be studied.

Working Benches.—Turning now to the details of construction of the fittings, the size suitable for benches, and their nature, has already been dealt with as necessary for laying out a plan. In height they are usually 3 ft. for adults but may be less for juniors; an inch or two, however, makes a great difference, and few will care to work standing at a table less than 2 ft. 10 ins. high. The tops are usually of teak, but less costly woods such as pitchpine make very serviceable tops and decrease the weight, an advantage if the tables are to be much moved. Seniors are seldom, and juniors hardly ever, given lockers and individual apparatus as for chemistry. It is therefore best not to fill in the space below the tables with cupboards for storage, unless the laboratory accommodation makes this imperative, in which case the doors to such cupboards should be placed on the side or end not occupied by the students, to admit of ready access while a class is at work.

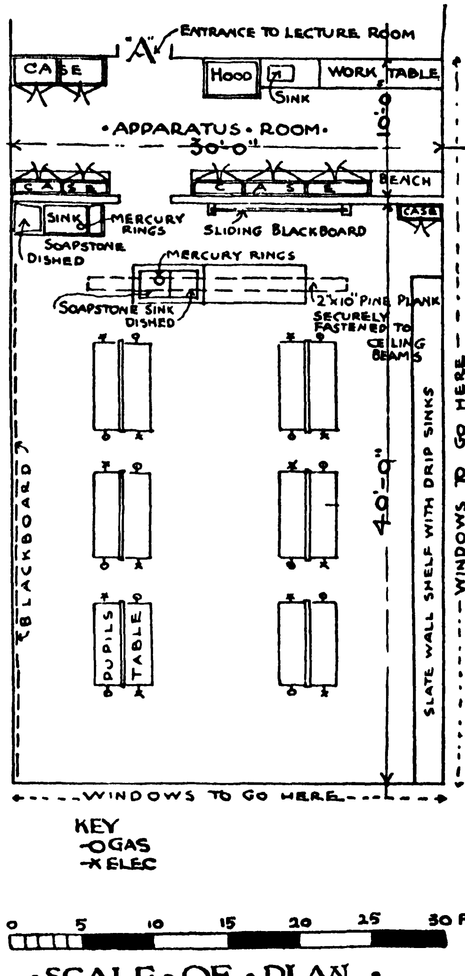


Fig. 49.—Physical Laboratory Plan, School House Department, Boston.

Sometimes a drawer alone is arranged below the top for each student, but very little use is generally made of it, and a good nest of drawers in one or more places in fixed fittings is often preferable. The writer's view is that as many of the working tables as

possible should be movable. They should have $1\frac{1}{4}$ in. teak or pitchpine or $1\frac{1}{2}$ in. yellow deal tops, legs $3\frac{1}{2}$ ins. square, which may be tapered at the bottom and should not be much more than 4 ft. apart; the framing should be strong, and if held by dragon pieces at the corners (**Fig. 50**) the tables will not be racked when moved, which is often otherwise the case.

If likely to be submitted to unauthorised movement the legs may be screwed to the floor (if of wood) by buttons. A bottom rail and cross braces are further necessary in tables of large size which are not fixtures, but unless arranged with one longitudinal centre rail attached to two end rails, as in **Fig. 50**, they have the disadvantage of preventing stools being placed out of the way under the tables when not in use, and when gangways cannot be on a generous scale this is important. If movement is desired the gas and other services must of course be arranged to admit of these being supplied from ceiling or floor or from wall connections.

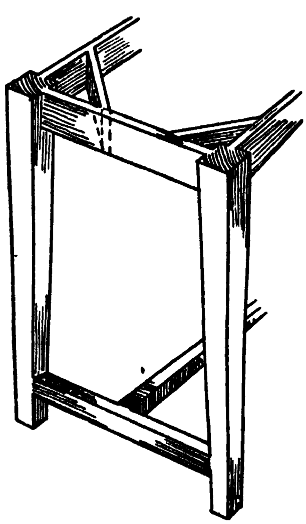


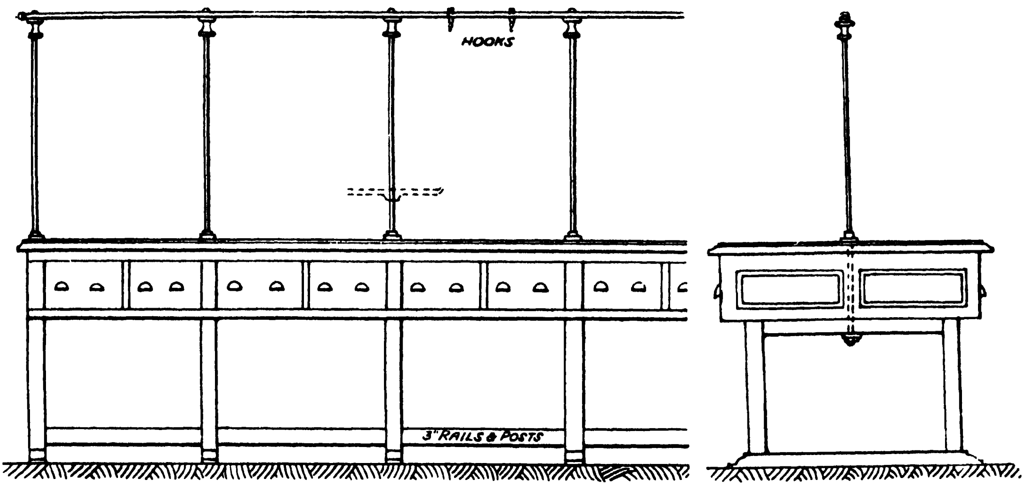
FIG. 50.—Framing to Physical Laboratory Tables.

Toe space should be usually provided where cupboards are placed under working benches but the top should overhang the framing by not less than 4 ins. on at least one working side to admit of clamps being secured for holding apparatus. A groove round the top is often provided to catch spilt mercury, but it is probably better to omit this and perform experiments involving mercury in a loose shallow wood tray supplied to each student as required.

Suspension rails of wood or metal down the centre of double benches, and 3 or 4 ft. above them, are sometimes used for attaching apparatus, mostly in connection with mechanics. A detail of such rails formerly used at the Addey and Stanhope School (**Fig. 47**) is shown in **Fig. 51**, and an American physical bench possessing such rails, designed by Messrs. Alison and Alison, who contributed the drawing, is shown in **Fig. 52**, while **Fig. 53** shows the very massive movable rail adopted by the Boston Schoolhouse Department.[1] Probably, the balance of opinion in this country is against these rails, though means for suspension on a more limited scale

[1] From the report of this Department, 1916.

against some wall of the laboratory is often desirable. If it is felt that the space below the tables is too valuable to be wasted altogether, then it is best to make the benches with cupboards, fixtures nearest the walls and retain the movable tables in a group so that on occasions a clear space of reasonable area may still be obtainable if wanted. Another reason for flexibility lies in the fact that, while teachers come and go the building remains, and a successor will often disapprove his predecessor's scheme of laboratory arrangement.



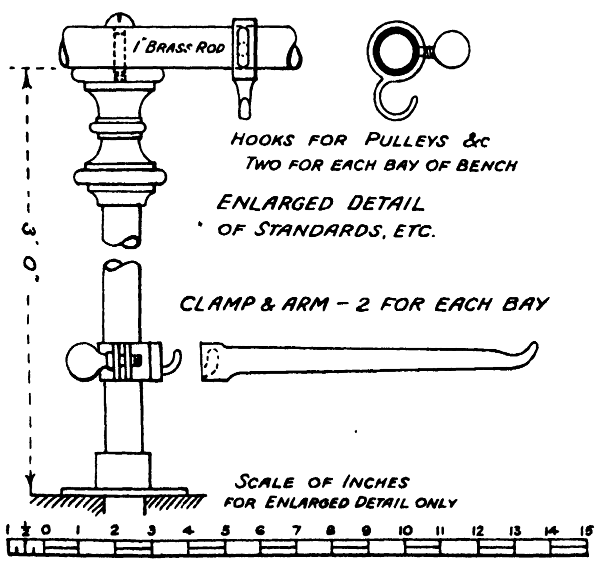


FIG. 51.—Detail of Rails to Physical Laboratory Tables used at Addey School.

Apparatus Cupboards.—Physical apparatus varies in size from things such as pins and cotton to others occupying three or four cubic feet. One or two shelves 4 ft. long and places 5 or 6 ft. high, the latter for storing long

tubes, rolled diagrams, and the like, should be provided, and it should be possible to adjust the shelves. This is not often necessary, and probably the use of substantial wood ledges screwed to the vertical sides are better and certainly cheaper than many of the patent rachet systems. These cupboards should be 15 to 20 ins. deep and have backs and glazed doors, the bottom shelves should be several inches above the floor to avoid breakage and dust. Doors are best hinged, but in confined situations may slide, in which case running wheels should be let in at the bottoms to facilitate movement. A good deal of dust may be excluded, provided the cases are carefully made, by rebating the framing or putting a stop all round.

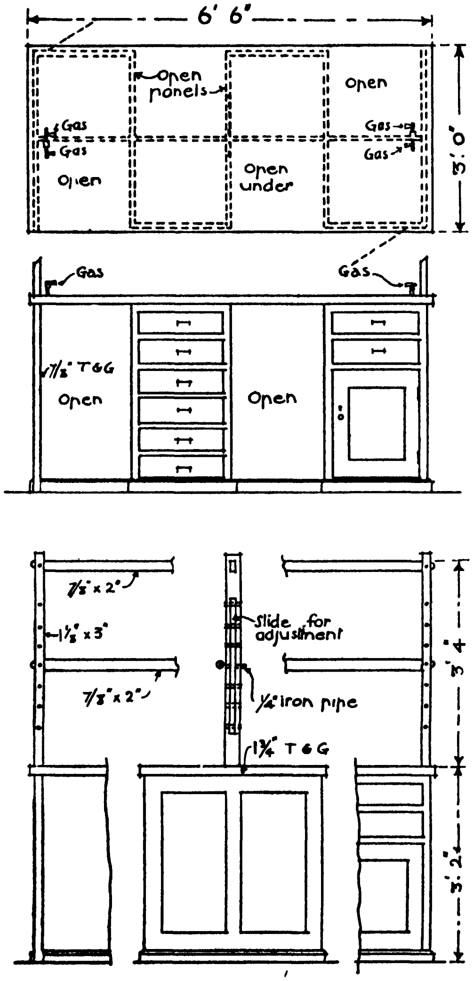


FIG. 52.—Bench Rails, School in California.

Ladders to High Cupboards.—In the case of high cupboards which require a ladder, a good flat space, say 6 ins. wide, must be arranged, against which the top of the ladder (usually provided with a padded bar) can rest. The physical laboratory at Charterhouse School has a range of glazed cupboards against the ceiling at some height over a working wall bench, which are ingeniously approached by a step ladder fixed at the top by rings to a continuous iron bar at the bottom of the cupboard, and with castors on its feet by which it can be rapidly drawn along clear of the bench below till opposite any desired point. The ladder resides out of the way at one end of the room beyond the termination of the wall bench when not in use. Very light ladders capable of sustaining a heavy man may be made by embedding on the under-side of

the styles (sides) a $\frac{1}{4}$ in. steel wire rope firmly secured at both ends, when any tendency to bend is resisted by the tension thus developed in the rope.

Cupboards in ill-lighted situations should be painted white inside. Where apparatus is wanted in two adjoining rooms it might occasionally be advantageous to make the cupboards part of the dividing wall, with shelves running through and glazed doors on both sides. This would aid illumination, cleaning, and transference, and would enable a deep cupboard to be effectively employed.

Drawers. — Certain things, such as pins, corks, small blocks of wood, and thermometers are best kept in drawers, and if each drawer is designed to contain specific things for a whole class it much assists working arrangements. Failing directions a dozen or so drawers of small size, say about 15 ins. wide by 18 ins. long, and varying from 2 ins. to 6 ins. deep, will be found useful.

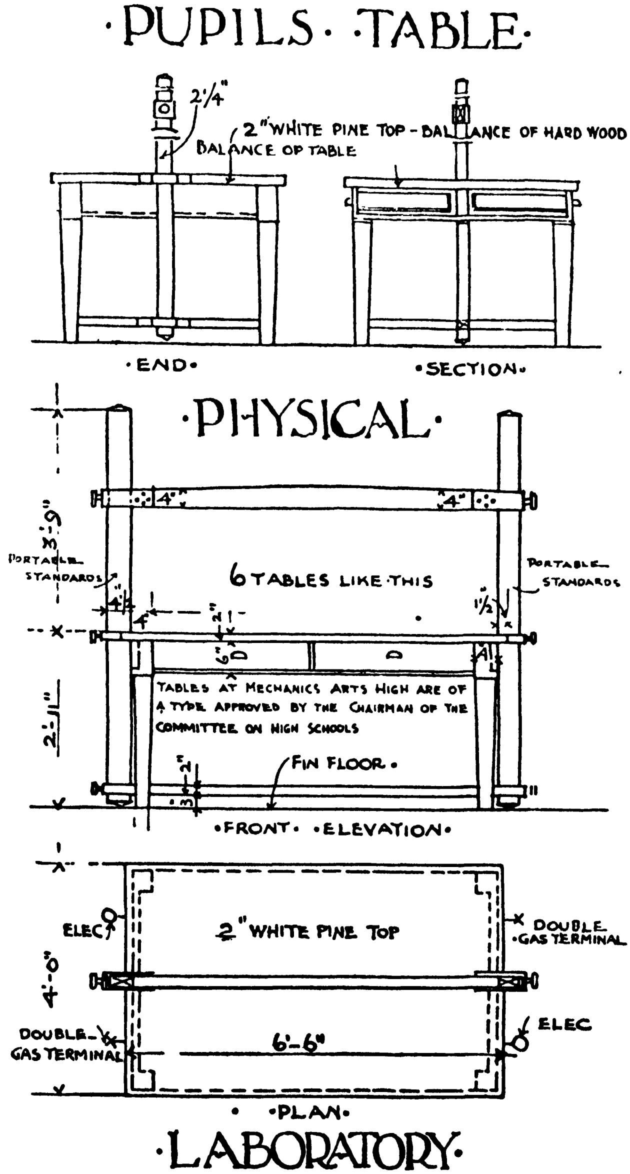


FIG. 53.—Laboratory Tables Adopted by the School House Department, Boston, U.S.A.

Runners and continued sides or buttons in connection with drawers have been referred to on page 30.

Sinks.—One large sink, say 5 or 6 sq. ft. in area, in a central position will serve an elementary laboratory, but it should have several water taps, say two at ordinary height and two about 24 ins. above the sink bottom to admit tall apparatus. A good-sized draining board, part of which may be covered with lead for vessels containing acids, should be provided. The top of the sink should be about 2 ft. 6 ins. above the floor. Usually of white glazed ware, the sink may, however, be lead lined or even of wood if kept moist and pitched. Sinks should not be placed on the working benches, which require as large an unencumbered surface as possible.

Balance Shelves.—Balances sometimes stand on a fixed detached bench with cupboards below, but are preferably on wall shelves supported by brackets. These have been discussed in the previous chapter, page 54.

Wall Fixtures.—Sometimes screwed sockets are built into the walls so that wood uprights can be bolted thereto as required, or permanent uprights about 3 ins. wide and 1½ ins. to 2 ins. thick may be placed in suitable positions round the room. Their utility depends upon the work proposed and the free wall space from say 6 ft. to the floor which is available. At Manchester Grammar School wrought-iron clips are attached at intervals to the flanges of the steel joists at the ceiling level. These clips terminate in plates pierced with holes for attaching apparatus.

Demonstration Table.—Ideas differ as to the desirability of tables for demonstration in physical laboratories. If provided, they are made like lecture tables of small size and usually have a sink, and stand on a platform about 8 ins. high. It is convenient to place the electric controls under or behind this table, and here on the wall the blackboard will naturally find a place (see page 39 for description).

Lecture Theatre.—There is no essential difference in general arrangement between lecture rooms required by the different branches of science, and as these arrangements have been fully discussed in the preceding chapter (pages 40-50) remarks here may be confined to matters of detail special to physics. Everything which has been said about acoustics, seating, and general dimensions, lantern, blackboard, and diagram requirements, hold good for any room for experimental demonstrations. A fume cupboard is seldom necessary in a physical lecture room, nor is a down draught on the table,

but in place of the former, behind the moving blackboards, a glazed cupboard opening to both lecture and preparation room and resembling a fume cupboard but for the absence of services and flue, is often provided for keeping dry frictional electric apparatus until required for use. The best means of keeping a dry atmosphere in such a cupboard is by warming the air, most conveniently effected by lamps or other form of electric radiator placed below the cupboard in an incombustible enclosure, the cupboard having a false bottom of perforated slate or enamelled iron. Alternatively, instead of this cupboard, a hot plate may be provided on the lecture table. This may be designed as a permanent part of its surface with electric radiators below.

Combustions and similar operations involving much radiation on the table top are not so frequent in physical as in chemical experiments, hence an area of incombustible material is less necessary. Again, the use of water is more restricted and a single sink and smaller number of supply cocks and drips will be sufficient. Gas also is rather less in demand. On the other hand, the electric supply services may be greater and are certainly required to give greater latitude.

Dark Blinds.—Means for darkening rooms are required to some extent by every branch of science, but chiefly in the domain of physics, hence this subject is discussed here. It is in the lecture theatre and in laboratories devoted to the study of optics that dark blinds are chiefly necessary. Ordinary union blinds are not sufficiently opaque, and specially treated black cloth is requisite. As blinds are often wanted for a short interval only, rapidity of action is very desirable, and occasionally they are operated by small electro-motors as in Fischer's chemical lecture theatre, and the physiological laboratory, Cambridge. For operation by hand, spring rollers are very desirable and some form of groove in which the edges can run is also required to exclude light; this is generally a wood casing, which should be deep and wide enough to take the blind lath, without fear of its jamming or coming out. It should be painted a dead black internally to absorb any light which may pass round it. These blinds are usually fixed at the top of the windows, with rollers, in wood cases screwed to the window linings, to exclude any light above them, but they may be fixed at the bottom, with a pulley at the top, over which the cord is drawn. They may also be placed horizontally in the centre, arranged in two sections, one to pull up and the

other down. This, of course, involves a considerable bar across the window but has occasional advantages, as where a window with a heavy transom with pivot hung lights above it has to be fitted with blinds. In such a case the reveals (window recess) will probably be deep enough to allow the side casing for the upper portion to be placed on a slant, so that the blind may draw in towards the room, leaving a triangular space between itself and the window sufficiently large to enable the top lights to remain partially open behind it. With such an arrangement, two or three taut wires would be desirable from the blind casing to the ceiling, to prevent the blind being forced out of the side casing by air currents. Blinds may also be hung in pairs on vertical axes at the sides of the windows and arranged to slightly overlap in the centre, where they are secured. If windows are very wide and horizontal blinds are adopted two blinds divided by a central vertical casing are desirable, as a tendency for wide blinds to come out of their side casings always exists. Skylights need special care if requiring blinds which are usually horizontal and drawn across several strong wires to prevent them from sagging. There seems no reason why heavy black curtains hung on rods which overlap across the window centre, or better on rails and pulleys, should not be used, the back vertical edges being fixed light-tight to the window casing. Such curtains would at least seem most suitable for very wide windows. From the above remarks it will be evident that this blind work should be executed by a firm with experience in laboratory requirements.

Preparation Room.—Cupboards and good table space are the essentials for a preparation room, a sink is also necessary, though it may be smaller than for chemical uses. This room often has to serve also as a workshop, but if this is separately provided the two should be near one another. If no special place for dealing with diagrams exists, a large rather low table with large shallow drawers will be found valuable. The cupboard space necessary will depend on such provision elsewhere, but there is always certain apparatus confined to lecture use and this should find a home here. A fume cupboard is hardly necessary.

Balance Room.—The description of a balance room used in a chemical department holds for physics, but cupboards under the shelves, sometimes found for chemistry, are not required for physical work. As already stated, in a small physics scheme a balance room is not a necessity.

Workshop.—A workshop, though it be only a room 10 ft. square, is a great asset and should be fitted with a carpenter's bench and rack for tools, a light metal turning lathe, small table drill, a side bench for general storage, and a small combustion bench with hood and flue, provided with a good gas supply. Gas is required for a small muffle furnace for annealing, for heating soldering irons and for a blowpipe (usefully installed here if not in the preparation room). A wood-block floor is desirable to reduce damage to tools which may be dropped.

Optical Room.—An optical room is necessarily small, since if a number of students are working in it together with artificial light it has no merits over a general laboratory. Usually designed for two or three workers its chief fixture is an optical bench consisting of a pair of wood or metal rails with a scale in inches and centimetres attached, upon which apparatus slides. These rails are usually part of the apparatus, and supports, in the form of a strong shelf about 15 ins. wide or merely brackets at intervals, are alone generally required as fixtures. Length is the great asset of this room and 20 ft. will be appreciated if obtainable. A firm wall bracket or pier, as described under "Advanced Laboratory," is often placed here for a galvanometer. The walls of this room are generally dead black. At the South-Western Polytechnic, London, where this is an internal basement room, a special flue is provided open to the sky to admit of the use of a beam of natural light. This also serves to ventilate the room, which is very necessary, work in the dark having an oppressive effect much relieved by a current of fresh air.

Advanced Laboratory.—The fittings of this room do not greatly differ from those already described for a general laboratory, but more space per head is necessary, and as work requiring entire freedom from vibration is more requisite here, in addition to wall brackets, one or more masonry or brick piers with slate tops may be required. These piers, about 2 ft. to 3 ft. square and hollow internally, are carried down to solid ground through the floor which they clear by a fraction of an inch, terminating in "footings" (brick projecting courses) and concrete. The nature of this termination will depend upon whether the ground is free from vibration or not. If it is, the concrete rests directly upon it, but if not, upon a bed of dry sand confined by a wall of concrete or brick, such sand bed being 1 to 2 ft. thick. **Fig. 54** illustrates the base of the piers used at the physical laboratory of Urbana

University, Illinois, which is described in Chapter VI, and upon which a very special amount of care was bestowed. Some general comments on the subject of vibration have been made on page 74.

Accumulator Room.—In all large schemes a special room is necessary for accumulators which are often required to supply very heavy currents. This room should have an asphalt floor laid to fall to a drain so that it may be hosed out. It should contain no metal fittings (apart from those of cells) as the atmosphere is often charged with sulphuric acid spray. At Bristol University this room is provided with fixed glass louvres set directly into the stonework of the windows to obviate both metal and paint and insure permanent ventilation, and the door is covered internally with ruberoid sheeting. To aid ventilation a fan is sometimes installed. Strong wood framing is generally used to support the glass cells which may be in two or three tiers. The number and size of these cells varies considerably and depends upon the scheme of work and funds available. In a school, half a dozen small cells may answer for all the low voltage demands, occasional heavy currents being taken from the mains through suitable resistances. A further account of accumulators and their arrangement will be found in Chapter V.

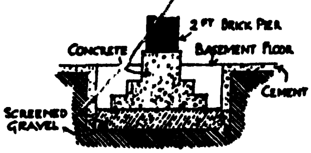
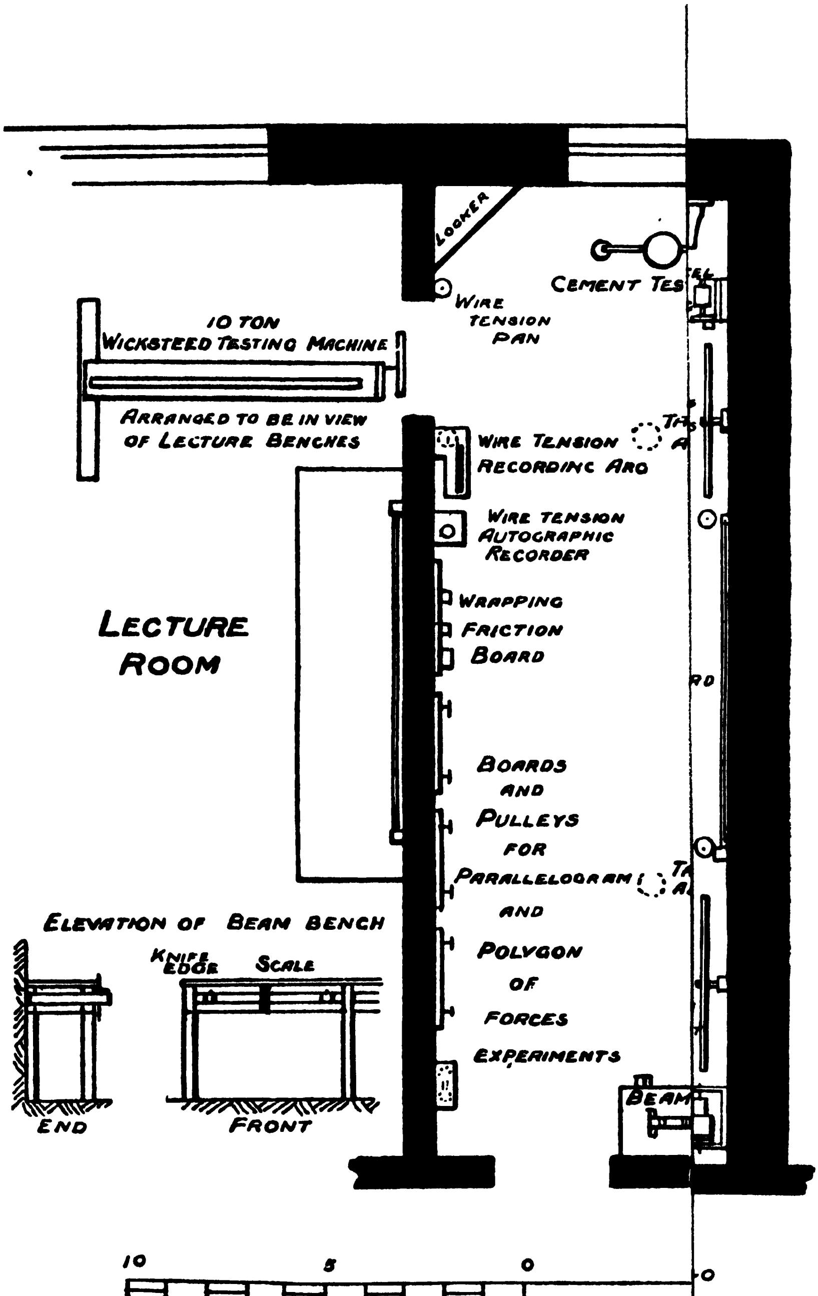


FIG. 54. — Foundations for Physical Laboratory Piers, Urbana University of Illinois.

Photographic Room.—Photographic work is sometimes carried on in the optical room in which the necessary sink and supplies are provided, but a special room with two doors separated by a lobby and a window with suitable orange-tinted screens and dark blinds is desirable. Though complete darkness is not essential for lecture purposes or usually for optical work, where sensitive plates have to be exposed the conditions are naturally of a very stringent character. For night work an electric lamp in series with a resistance, or two lamps, one of a voltage higher than for the general lighting, will be found useful to admit of a dimmed or normal light as desired. These lamps are either of tinted glass or are enclosed by coloured screens.

Mechanics Laboratory.—In a mechanical laboratory a comparatively small amount of work is done seated at specific tables, hence a bench for each worker is hardly necessary. Much of the apparatus is disposed round the walls of the room, very little space upon which can be devoted to benches or


LOCKER
CEMENT TES
WIRE TENSION PAN
10 TON WICKSTEED TESTING MACHINE
ARRANGED TO BE IN VIEW OF LECTURE BENCHES
WIRE TENSION RECORDING ARG
WIRE TENSION AUTOGRAPHIC RECORDER
WRAPPING FRICTION BOARD
LECTURE ROOM
BOARDS AND PULLEYS FOR PARALLELOGRAM AND POLYGON OF FORCES EXPERIMENTS
ELEVATION OF BEAM BENCH
KNIFE EDGE
SCALE
END
FRONT
BEAM
10
5
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e page 91.

cupboards. A solid floor is more necessary for this than other departments, but as a rule special foundations are not required. A few tables at which notes can be made should be provided, but these should be movable, and as much free space as possible retained for use when occasion arises, though some machines will necessarily be fixtures in the central area of the laboratory. **Fig.** 55 shows a plan of the mechanical laboratory at the Battersea Polytechnic,[1] which gives exceptionally full details of the apparatus used in this department. For the determination of what is known as Young's modulus—which in a physical laboratory usually takes the form of measurement of the stretching of wires with various weights—a great length of vertical wire is necessary. If, therefore, it can be arranged that a space running through two or several stories is devoted to this experiment it will be a great advantage. Little more than the area of a chimney flue is necessary and may sometimes be obtained conveniently on a staircase wall adjoining the laboratory. Access at the top is required (though not for the students), but no intermediate openings are necessary.

Heat Laboratory.—A special room is sometimes provided for experiments on heat. The chief difference between this and a general laboratory lies in the provision of a steam supply and a larger number of water supplies and wastes to admit of the use of running water required to circulate through apparatus. Benches are preferably of incombustible material, slate being often used, though tiles on concrete are probably better, and these benches, for convenience in arranging supplies and wastes, are sometimes placed round the walls. A better arrangement is to supply steam, water, and wastes to a narrow wall shelf adjoining either fixed tile topped or movable wooden benches, at suitable intervals at right angles to the walls. This admits of better lighting and supervision and of more flexibility.

Electrical Laboratory.—The concentration of electrical work in one laboratory has the advantage of reducing the outlay in heavy electric cables usually regarded as necessary in modern investigations. Such a room should naturally find a place as near the accumulator room as is practicable, and unless a special switchboard room is provided for the building elsewhere the board is one of the main laboratory fittings. Something will be said in Chapter V about the general cable and board arrangements. The fittings

[1] Contributed by this Institution through Mr. Kelly of the Board of Education for Ireland.

otherwise bear a close resemblance to those of an advanced laboratory. A great deal of mirror galvanometer work will be done in this room, hence ample provision should be made for these instruments on wall brackets, and if the lamps and scales required can be placed elsewhere than on the students' benches much saving of room will result. At the South-Western Polytechnic, London, Dr. Lownds has arranged the galvanometers along one side of the room about 3 ft. apart, on a slate shelf. Attached to the under side of the shelf is an arm of oak about $1\frac{1}{4}$ ins. square and 2 ft. 3 ins. long, which can move in a horizontal plane and thus be swung out of the way. This arm, which is about 2 ft. above the bench, carries at its free end a semi-transparent scale and below it a small electric lamp and lens which illuminates the scale by reflection. Wires are run as required from the galvanometer to fixed terminals on the shelf. The tables are all movable. **Fig. 56** shows a plan of the dynamo and engine-testing laboratories at Battersea Polytechnic,[1] which, though somewhat outside the scope of this book, is of interest as indicating the space required for various machines.

It will be found advantageous generally to leave one or two holes in internal walls connecting laboratories to admit of cables or temporary pipes being carried through when required without cutting the walls. Such holes need not exceed 3 ins. in diameter.

Other Rooms.—Research Rooms.—Few special comments are requisite touching the other rooms suggested as necessary in a complete physical department after the description already given. For research, plenty of free space is desirable, hence tables should be movable, and gas, water, and electric services confined to narrow wall benches or shelves as far as possible. If research in certain branches of physics can be confined to specific rooms some economy may result in the provision of heavy electric cables, dark blinds and ventilation, but if this is not possible, water, possibly at two pressures, gas for ordinary and small furnace work under a hood, variable electric supply, dark blinds, and possibly a steam supply will probably be wanted.

Store Rooms.—In a small scheme stores are not as prominent in physics as they are in chemistry, but for a large scheme a room for unpacking

[1] London Polytechnic courses on Engineering are about to be concentrated at this Institution, hence Figs. 51 and 52 may require modifications to represent actual conditions.

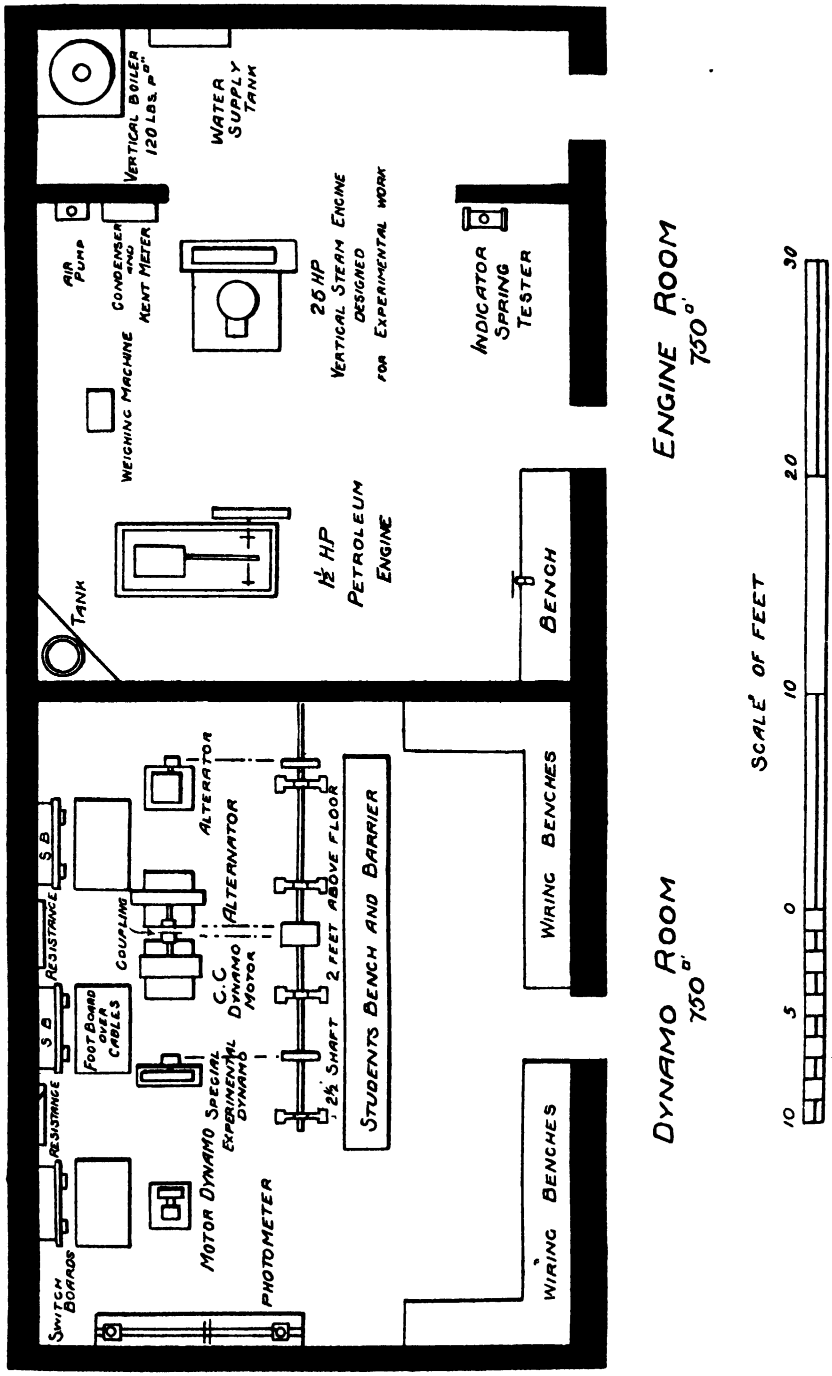


FIG. 56.—Plan of Dynamo and Engine-Testing Laboratories, Battersea Polytechnic.

in addition to an actual store room may be requisite, and if this accommodation is provided on more than one floor, connection by hand lift or special staircase will be useful. The fittings should consist of glazed cupboards, a few drawers, and a table or bench. When the height of stories is considerable galleries or mezzanine floors may be contrived to economise space.

CHAPTER IV.

THE REQUIREMENTS OF BIOLOGY AND GEOLOGY.

BIOLOGY includes in its widest sense the study of both animals and plants under the divisions zoology and botany. From the former the study of man is generally understood to be excluded, this being relegated to medical and surgical science. In the modern sense physiology may also be excluded from zoology, which is not held to include experimental work on living vertebrates. Such work, which forms the main feature of physiology, has developed so much in recent years that this subject now possesses the status of a separate main branch of natural science to which a department may be entirely allocated. Physiology in this modern sense includes the study of living animals including man, and in the absence of a special botanical department may also include the physiology of plants, and such work involves much equipment of a chemical and physical character.

For the purposes of this book, however, zoology and botany are regarded as including respectively the physiology of animals and plants, while embraced under the term "geology" are its allied subjects physiography and mineralogy. In comparing the requirements of these subjects with those of chemistry and physics, it may be stated broadly that their classificatory nature renders museum equipment a matter of great importance, often involving considerable outlay, but that otherwise, apart from special inroads into the subjects of the previous chapters, the fittings and services necessary are much simpler in character. Special attention is again necessary in the matter of lighting owing to the prominence of microscopic study. Individual apparatus required is but little, which carries with it a considerable reduction in the necessity for movement on the part of the students.

It will be convenient to divide this chapter under the headings of Botany, Zoology, and Geology, but the somewhat formidable list of rooms covering these subjects will not involve a proportionately lengthy discussion, and it is only in schemes of university rank that a general laboratory does

not serve for several of the different studies enumerated. Thus one properly lighted laboratory can serve excellently for elementary work in all the branches of both botany and zoology and also for much work in geology. In the lists of rooms the various specific laboratories required in larger schemes are to be regarded as taking the place of a general laboratory.

BOTANY.

The following rooms may be comprised in a botanical department :—

[1] 1. Elementary laboratory.
1. Lecture room.
1. Preparation room.
1. Museum.
1. Greenhouse.
[1] 2. Advanced laboratory.
2. Herbarium.
2. Workshop.
Physiological laboratory.
Research laboratories.
Chemical laboratory.
Mounting room.
Incubator and Sterilizing room.
Library.
Dark room.
Store rooms.
Staff rooms.

Elementary Laboratory.—A steady light for microscope work is essential in a botanical laboratory, hence a north aspect is desirable, though if only used at specific times of day this condition may be modified. Unless the room is high and not of great width top light is necessary to give sufficient central illumination. For this reason among others the subjects of this chapter are generally given a top floor in a composite scheme. The fittings of the laboratory are simple and may consist of plain continuous benches 2 ft. to 2 ft. 6 ins. wide, devoid of drawers and lockers, 2 ft. 9 ins. being enough bench length for each student. The height is usually 2 ft. 9 ins., occasionally as little as 2 ft. 6 ins. if low stools are used, but in a recent university school 2 ft. $10\frac{1}{2}$ ins. has been adopted. The bench top may be deal or hardwood, while a covering of linoleum makes a good easily cleaned surface. A ledge two or three inches high at the back is desirable to prevent apparatus being pushed off. Sometimes a plate of opal glass about 6 ins. square is let into the bench near the front to assist in the examination of minute specimens or those requiring a white background. Sinks in the

[1] As in previous chapters (1) indicates the minimum requirements for a small scheme and (1) and (2) rooms desirable in a large secondary school. A lecture room and preparation room, common to all branches of science, are of course sufficient in a small scheme.

benches are not necessary, neither is gas for heating, but both should be provided in one or two accessible parts of the room. For night work a separate light is required for each student, and the best type is a flexible standard electric filament lamp. Ordinary pendants are useless owing to their inevitable motion. For microscopes nests of cupboards about 9 ins. long, 6 ins. deep and 16 ins. high are required, unless the instruments are in their own portable cases, which may stand on shelves. This provision is sometimes made on the walls and sometimes by a limited amount of filling in with cupboards under the working benches.. Linoleum forms a very suitable floor covering. **Fig.** 57 shows the elementary laboratory at Cambridge University, the plan of which is given in Chapter VI.

FIG. 57.—Elementary Laboratory, Botanical School, Cambridge University.

Lecture and Preparation Room.—The general description of a lecture theatre given on pages 40-51 applies to botany, except that the services may be much reduced and a fume cupboard, down draught, and electric supply (except for the lantern and lighting) may be dispensed with. The apparatus employed is also less than for most other subjects, hence few cupboards and drawers below the tables are wanted.

The preparation room will be largely concerned with diagrams and in a small scheme will probably serve also as a mounting and store room. A large low table on which diagrams can be spread, with drawers for their reception below, together with shelves and a sink, are its chief fittings.

Museum.—A public museum is usually arranged chiefly with a view to the display of its contents in order to engage the interest of the casual visitor,

and although such display may have some advantages in arousing a serious interest sufficient to induce a wish to study, in educational institutions display should be subservient to teaching facilities. In a large collection a part may be specially allocated to students' work, while still leaving the main collections at disposal for general exhibition. The curator can alone formulate the requirements in the matter of fittings, but whatever his system of classification it will be found that the size of specimens will occasionally interfere with it and demand special cases or stands. Nothing is better for uninterrupted study than a series of bays formed by high cases at right angles to the window walls, between which a table case with a sloping glazed top is often placed, or an ordinary table with chairs in such bays as contain students' collections. If the room is wide enough, central cases, conveniently devoted to larger specimens, may be placed parallel to the window walls down the centre of the room. From the above remarks it will be seen that a long gallery, lighted on both sides, makes a most suitable room for collections. The floor may be of wood or linoleum on cement which is more conducive to silence. General diffused artificial lighting may be adopted, but some individual lights should be provided for students' use in addition. Glass shelves in the cases are advantageous in lessening obstruction to light by fittings, and for botany dead black backgrounds are often advocated for the majority of specimens, though, of course, absorbing much light otherwise reflected. The materials for and elaboration of the cases will be usually governed by the funds available, but it is better to have a few well-made cases than a large number of inferior ones for collections of any value, because the entrance of dust not only entails labour but permanently spoils many specimens. Oak or mahogany are usually employed, advocates of these woods being fairly equally divided. The latter is less likely to warp, but the attrition of moving parts, such as drawer sides, produces after a time a fine red dust which is a disadvantage. Bass wood or pine may also be used where economy is desirable. Drawers, which are seldom more than about 3 ins. deep, are sometimes covered by glass in a frame which can only be removed when the drawer is pulled right out, an operation controlled by some special key or mechanism. That used at Charterhouse School, which consists of a hook which engages in a slot in the drawer runner, preventing removal without the application of two special bent lifters, is shown in **Fig. 58.** Another arrangement from a detail kindly contributed by Messrs. Prime of Cam-

bridge, and used in the Cambridge Geological Museum, is illustrated in **Fig. 59.**

The exclusion of dust is much helped by forming a raised bead on frames and a corresponding groove on doors or lids which close against them, shown in **Fig. 60.** The great importance of the dust exclusion has led to many devices, and since its entrance is due chiefly to differences of air pressure causing a current at times to flow into the cases, openings are sometimes made which are filled with cotton wool or other porous material to catch the

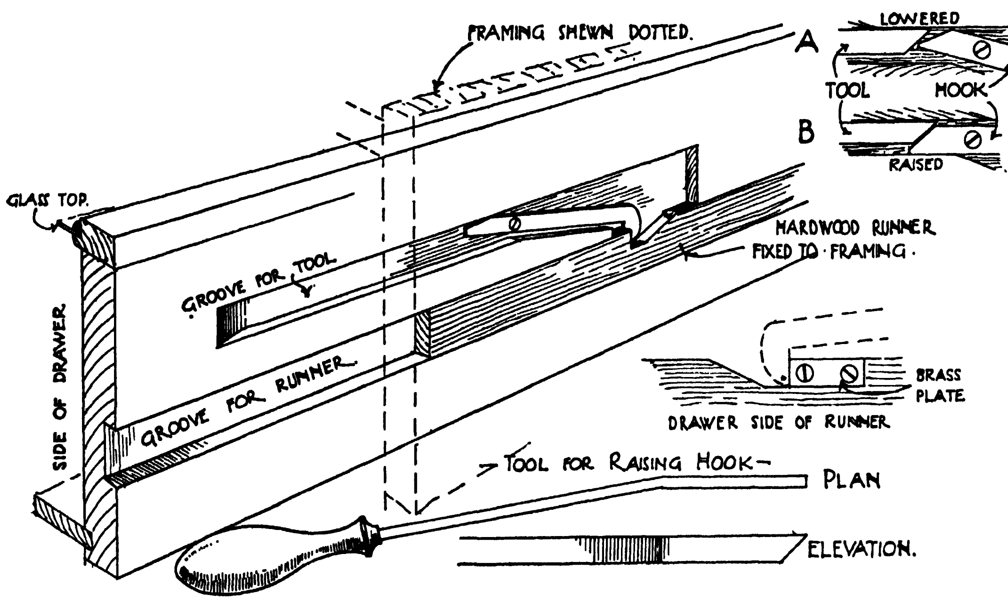


FIG. 58.—Method of Controlling Removal of Drawers in Use at Charterhouse School Museum.

dust while admitting free air access. Such arrangements, of course, require renewal of the absorbent material from time to time. When compressed air is available it might be worth while to consider supplying cleaned air to the cases, which could thus be kept under slight pressure to prevent the entrance of dust-laden air.

Cases should not be too deep, but the dimensions decided upon will be governed by the size of, and detail displayed by, the specimens, and an attempt should be always made to bring some of the specimens which contain much detail sufficiently near the glass to admit of examination by a

hand lens without removal, which will often obviate opening the cases for students' work. In table cases the glass must be thick enough to stand the pressure of an arm leaning upon it.

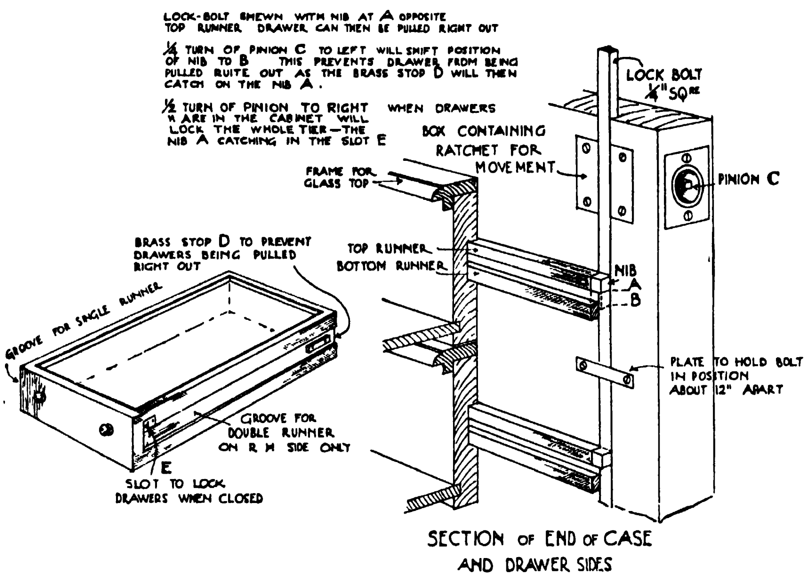


Fig. 59.—Method of Controlling Removal of Drawers, arranged by Messrs. Prime of Cambridge.

Greenhouse.—The roof of the building is the obvious place for a greenhouse, and a flat open area in addition should be provided for other work in which exposure to sun and air is desirable. Though sun is required for many purposes, for others it must be excluded, hence if the work warrants it, two houses may be provided. In the new botany school at Cambridge, the house for sunless work is sunk in the building one storey below the roof, external access being provided to it off a small flat on the top floor of the building (see Chapter VI). The ordinary requirements in the matter of heating and water must be supplied, and naturally the impervious floor must be laid to a fall and drained.

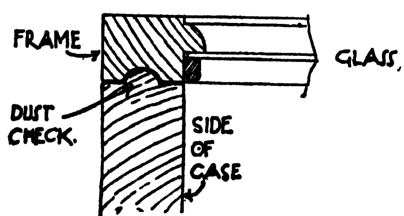


Fig. 60.—Dust Check to Lids of Museum Cases.

Advanced Laboratory.—An advanced laboratory will probably be used chiefly for morphology—work on plant structure—but in the absence

of other rooms for advanced work, physiology and chemistry may also be studied here. For morphology the fittings will not differ greatly from those of an elementary room, but microtomes for cutting sections will involve a rather more liberal supply of water and gas on some of the benches, in connection with the making of slides. The higher microscope powers used will necessitate more attention to efficient lighting, both natural and artificial. In connection with the former, windows should never be divided into small squares when transmitting light for microscope work, as the image of the bars will appear in the picture and may be found difficult to avoid. If physiological and chemical botany are projected, the room should be fitted more like a chemical or physical laboratory.

Herbarium.—A herbarium, unlike a museum, is never arranged for display, it forms an immense plant dictionary in kind, the dried specimens being usually mounted on cards and kept in folders of about foolscap size, though some are necessarily larger. These are housed in nests of pigeon-holes a foot or so high, in which the folders lie flat one upon the other. The exclusion of dust from these specimens is most important, and as the doors are hardly large enough for beads, as described on page 100, they should be rebated and fitted very accurately. With a large collection, the arrangement of the cases to form bays with a window in each, may be followed, and a table, or at least a continuous desk on which the specimens can be studied, should be provided beside them. The natural lighting should be ample, but sunshine should be excluded, if not by the design of the building, at least by the provision of blinds, to prevent damage to the collections when exposed.

Workshop.—A general repair shop is necessary in any large scheme and should provide for small joinery work, and for glass blowing, such as can be done on an ordinary blowpipe table. If much physiological work is done, arrangements for light metal work, as already detailed on page 89, will also be advantageous.

Research Laboratories.—Special fittings for laboratories for botanical research are chiefly associated with physiological and chemical work. For the former, two water services to give both low and high pressure from roof tanks and the public mains respectively will be found useful. In addition to ordinary benches, a table with a raised edge for mercury experiments, and a bench with an incombustible top supplied with gas, will also be

necessary, while power leads for running small motors and the like should be provided. Sometimes a little forcing house, such as could stand on an ordinary table, is required in the laboratory itself for physiological research. Chemical botany demands the equipment of an ordinary chemical laboratory, but the extent and variety of glass apparatus and reagents is usually less than for general chemistry. Accommodation for balances must also be included. As work on living plants is conducted in these rooms they should be near the greenhouse.

Minor Rooms.—Dark rooms are required in a botanical department; these may be necessary for photographic purposes but are also required, in connection with physiological research, for optical work. For mounting specimens a room is sometimes specially provided, and should possess plenty of table space and a gas and water supply. For incubation and sterilization, incombustible benches are required for ovens and for heating under pressure, which is conducted in a large cylindrical vessel on a bench, which should only be raised slightly above the floor. Flues and hoods are desirable over such apparatus. Storage is not so necessary for botany as for some other subjects, but should be considered in the light of the trend of the department's work.

ZOOLOGY.

Broadly speaking, the requirements of zoology for teaching purposes in the matter of fittings and services are more, and in that of collections less,[1] than botany. The following rooms may be comprised in this department in which animal physiology is included :—

1. Elementary laboratory.
2. Lecture theatre.
2. Preparation room.
2. Museum.

Advanced laboratory.
Workshop and mounting room.
Tank room.
Greenhouse.
Research laboratories.
Operating theatre.
Battery and switch-board rooms.
Dark rooms.
Centrifuge room.
Compressed air room.
Library.
Store rooms.
Staff rooms.

Elementary Laboratory.—All the comments made on pages 96-97, in reference to lighting and benches, apply to zoology. The work done in an elementary laboratory will consist of simple dissections and microscopic

[1] Unless a large museum for display is required.

study. The dissections are largely effected under water in dishes, and should the student puncture an artery in the process, fresh water is necessary as the blood will render the specimen invisible. Hence more water is required than for botany, and though a sink for every student is not necessary, ready access to water without much movement is desirable. Gas on the benches is essential for the purpose of preparing slides. For this a hot plate consisting of a flat sheet of copper about 9 ins. by 4 ins., supplied with a Bunsen below capable of regulation, to give a very low diffused temperature to the plate, should be provided for every two students. If no lockers are provided under the benches, at least some pigeon-holes, allocated to individual students, are necessary. In American schools small nests of holes, 3 ins. by 3 ins. by 8 ins., are often provided to hold instruments.

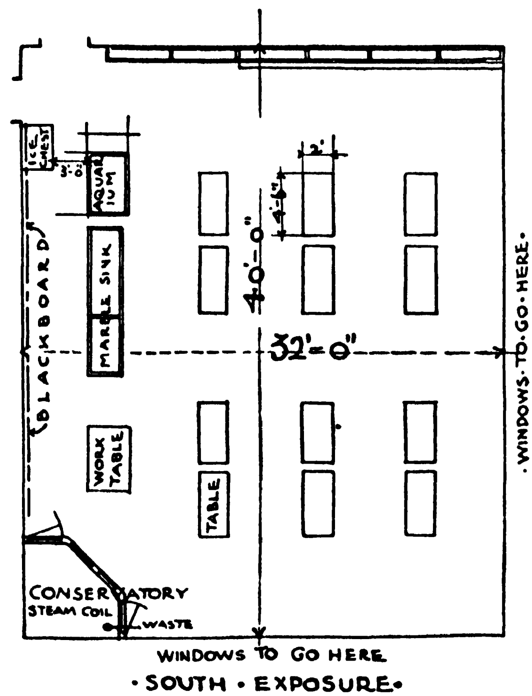


Fig. 61.—Laboratory Plan for Botany and Zoology adopted by the School House Department, Boston, U.S.A.

Fig. 61 shows a plan adopted by the Boston School House Department as a general standard in their schools for biological subjects. The laboratory area is about 1200 sq. ft., and one of its aspects must be due south. **Fig. 62** shows a detail of the standard tables and sink or tank used in such laboratories. For elementary work the tables, 54 ins. by 24 ins. by 30 ins. high, for two students, are covered with plate glass and the tank is of marble and of considerable size.

Lecture Theatre and Preparation Room.—For general lecture purposes a theatre such as would be suitable for physics is desirable for zoology, though the elaboration of drawers, cupboards and services to the lecture table will be regarded as unnecessary by many teachers. Where

much physiology is studied, the physical resemblance must be, however, a very strong one, a good supply of gas, sufficiency of water, electric service —direct current, if both kinds are not provided—a fixed galvanometer and screen, and ample diagram arrangements, are all necessary for this branch of the subject. Sometimes a tank is arranged on the top of the table with one or more glass sides for live specimens in water. Fig. 63 illustrates such a table, 9 ft. by 3 ft. by 2 ft. 10 ins. high, manufactured by the Kewaunee Co., U.S.A. The tank, glazed in front, is otherwise made of alberene stone. The fittings of the preparation room will be governed by the character of the lecture room, but its relation is not so well defined as in the older studies. At Bristol University, for example, Prof. Kent in his physiological department has thrown the preparation room into the lecture room itself to form a large free area behind the lecture table, which table, as previously mentioned, consists of movable sections. A great feature in

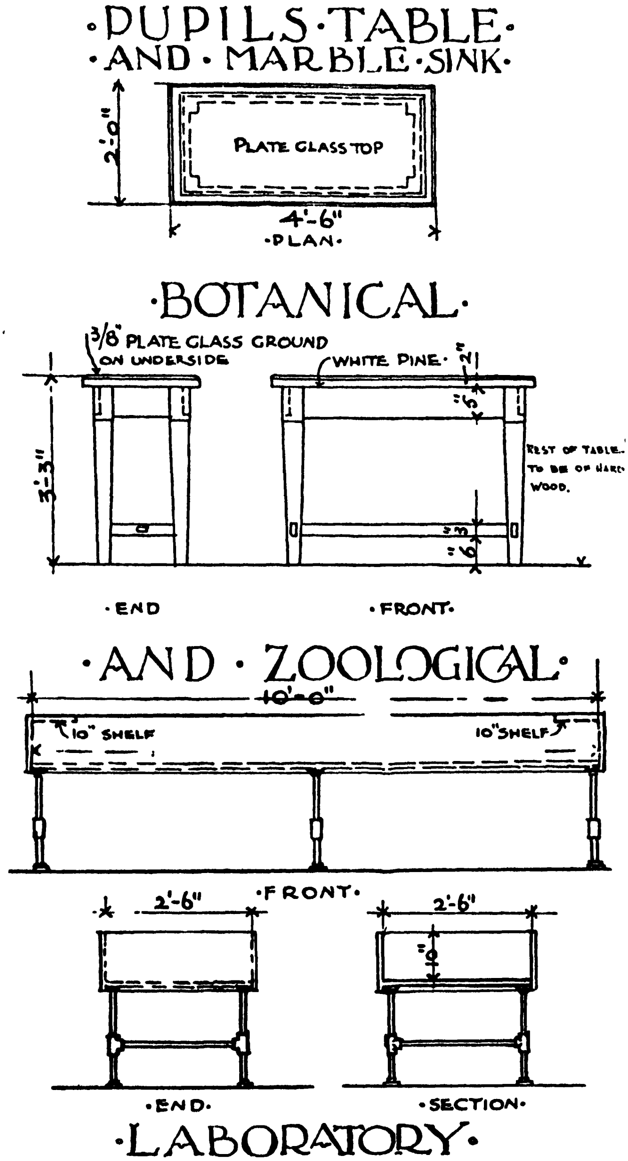


Fig. 62.—Botanical Tables and Zoological Tanks used by the School House Department, Boston, U.S.A.

modern biological teaching is the study of movement, with the aid of the cinematograph, which instrument may be suitably installed in the preparation room, surrounded by incombustible materials, a hole in the wall admitting the beam of light to the screen in the lecture room. Considerable space for diagrams is also necessary. In Prof. MacBride's laboratories,[1] which he was good enough to show the writer, these are suspended by hooks attached to a metal strip along the top of the diagram, from a central horizontal rod, in a series of cupboards about 5 ft. deep and 6 ft. 6 ins. high with sliding doors. The diagram surface is placed at right angles to the doors, and although 50 may easily be housed in every three feet length of cupboard, the subject can quite readily be seen.

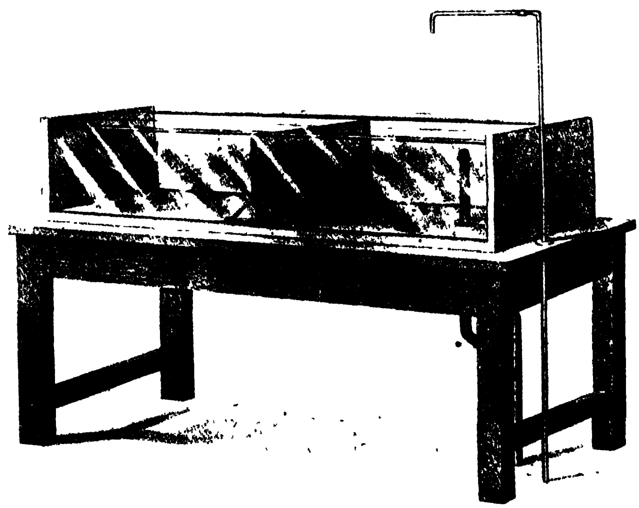


FIG. 63.—Tank Biology Table.

Museum.—The only additional comments on the subject of museums (see pp. 97-100) in special reference to zoology which seem necessary, refer to the use of sets of bones for individual student's use. Where a special room in connection with the laboratories or storage is not provided, a place may be reserved in the museum for a series of small boxes, usually about 12 ins. by 6 ins. by 6 ins., each containing a complete set of the bones of some small animal for identification. Though these will probably be used mostly in the laboratories, their location in the museum, which will contain complete skeletons set up, seems to have obvious advantages.

Advanced Laboratory.—In this room advanced histology (microscope work), embryology, electric stimulus and drum recording work, will probably be undertaken. As far as histology is concerned, the arrangements will

[1] Imperial College of Science, South Kensington.

follow those of the elementary laboratory, but rather more space should be allowed for each student. The drums are pieces of apparatus occupying about 12 ins. by 9 ins. of table space and are some 18 ins. high. They consist of cylinders rotating on vertical axes at variable speeds and are driven by a motor. Much attention to these arrangements has been given in the physiological laboratory at Cambridge, where a light horizontal shafting driven by a single motor on the floor is fixed on one side of each bench top. To this the drums are attached and put in motion by a clutch. Some of these tables are 25 ft. long with a drum for each student at 5 ft. intervals for advanced, and 2 ft. 9 ins. for elementary work. The tables should be about 3 ft. wide as the drum and shafting have to be deducted from the available space. In the instance cited the table height is 2 ft. 10 ins. A small cupboard and drawer may be placed below a part of the working space. Provision for galvanometers in the shape of wall brackets and screens is desirable, and for their use a part of the room should be capable of being darkened. An ice chest and electrically heated cupboard are also often required in this laboratory. Some enclosed and ventilated closet, which may be a separate room or merely a fume cupboard, is required for covering the drums with smoke from time to time for new records. This operation is performed by the laboratory attendant, hence the necessary accommodation need not adjoin the laboratory.

Workshop and Mounting Room.—A repairing shop is of course desirable, and this should deal with joinery work but may also have to serve for the mounting of specimens, in which case it should be large enough to admit of a separate bench in a good light for this purpose. Not only much time but often money may be saved by training an assistant in work of this character, and if he is expected to display interest in it, proper facilities should be provided. Such work includes not only the erection and articulation of skeletons and the bottling of specimens in spirits, but such matters as the arrangement of specimens in their natural environment, which gives scope for considerable artistic skill.

Tank Room.—The development of small amphibious creatures and their preservation alive for future use requires small tanks with water supply and often some aerating device to keep the water fresh. Two rooms may indeed be desirable, one to act as a store which may be in the basement, the other as a working room for observations. The latter will require tanks

which may take the form of large shallow sinks of glazed stoneware, or wood lined with sheet metal, or large bell-shaped glass jars may be preferred. **Fig. 64** illustrates the tank or aquarium manufactured by the Kewaunee Co. of U.S.A., which consists of two compartments of glass and alberene stone, 50 ins. by 24 ins. by 15 ins., on a table 58 ins. by 32 ins. by 30 ins. high. In the laboratory of Prof. MacBride, who has actually succeeded in breeding sea-urchins, the water is kept in slow constant movement by the stirring action of glass plates attached to a lever worked by an intermittent syphon. If a compressed air service is available air may be forced into the water through a rose opening. At Cambridge it has been found possible to keep marine animals in filtered sea water for three months without renewing the supply. The tanks used in the new laboratories at Cambridge for the purpose of storage are formed as a continuous row (shown in plans, page 183) against the wall of the room and are built in concrete with round bottoms and hinged ventilated wooden covers. **Fig. 65** shows a section through these tanks which have vertical divisions of concrete about 3 ft. apart and a small connecting pipe at the bottom of each so that the whole system may be flushed out into a drain on the external wall, by means of a water supply at the other end. A connecting opening is also provided near the top of the divisions as an emergency overflow.

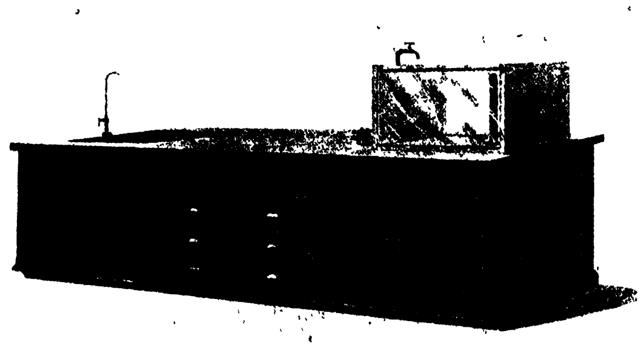


FIG. 64.—Tank Biology Table.

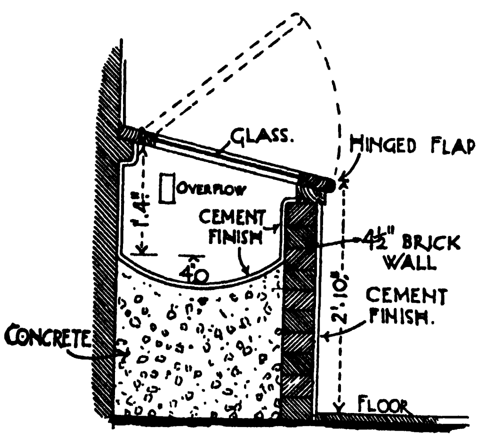


FIG. 65.—Amphibia Tanks for Stock, Cambridge University School of Physiology.

Greenhouse.—Where it is desirable to rear insects for zoological work a greenhouse will be necessary, and openings arranged to admit air while retaining the insects may be required.

Research Laboratories.—Fittings for research cannot, of course, be standardized: enough has been said of zoology proper and of physiology to indicate the character of the requirements in the way of fittings. The study of such subjects as respiration will involve the use of small motors for shaking and stirring apparatus, and wall space for mercury pumps. Electricity also plays a great part in physiological researches and will be required for shock timing pendulums and other purposes. Brackets for galvanometers, low incombustible tables for large water baths, open space with appropriate lighting for operating tables, and space for live boxes which may be a cube yard in size, are other considerations, while chemical physiology demands the fittings of a chemical laboratory and a balance room. Electric supplies may be arranged round the walls or in groups of pendant flexes from the ceiling, the latter plan being adopted at Cambridge.

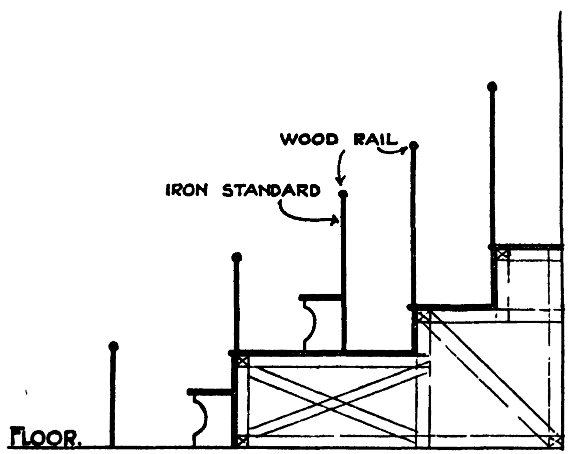


FIG. 66.—Section Through Seating to Operating Theatre, Cambridge University School of Physiology.

Operating Theatre.—Physiology requires opportunities for the detailed inspection of operations, hence, in addition to the lecture theatre for general work, a smaller room to hold perhaps forty or fifty students may be wanted, which is planned like a medical students' operating theatre, but the operating table is, of course, smaller. The seats are on steeply raised semicircular tiers, and usually the back rows have merely a high rail against which the students lean, standing. The table may be regarded as a piece of apparatus, and is not fixed. A sink, gas supply on an adjoining shelf, electric supply, and a galvanometer bracket are required in this room. **Fig. 66** shows a section through the seating in the operating theatre of the physiological department at Cambridge, the plans of which are given in Chapter VI.

Dark Room.—A dark room may be required for optical work, such as, experiments on vision, for study of the heart, for X-ray work, and for photography. In a large scheme, several rooms for these respective purposes will be wanted. The general remarks made on dark rooms for other subjects apply to the arrangements necessary.

Centrifuge, Compressed, Air and Store Rooms.—In many experiments separation of solids and liquids is most conveniently effected by rotation on a vertical axis at a very high speed, for which a motor and centrifugal machine, often belt driven, are employed. For air compression, necessary for aeration and other purposes, a compression pump driven by a motor is required, attached to a storage cylinder, which feeds the mains and assists in keeping the pressure—usually between one and two atmospheres—constant.[1] For both these requirements small basement rooms are suitable. Storage is necessary not only for the purposes already mentioned, but for subjects kept in spirits which are obtained possibly in some quantity at one time when available, and are gradually used for dissection by the students. A separate room, which should be capable of isolation in case of fire is, desirable for this purpose on account of the large quantity of alcohol involved. Sometimes a special cold storage room with thick cavity walls and double doors is included in the department, and where much chemical and physical work is done, storage for glass, chemicals, and instruments will have to be considered on the lines laid down in previous chapters.

GEOLOGY.

Apart from museum accommodation, special equipment for the teaching of geology is usually confined to institutions of university standing. Physiography, however, which forms a link between geography and geology is—or should be—largely taught in schools. Apart from museum demands, the requirements of geology in the matter of special fittings are not great. The subject falls into three branches : stratigraphy—the study of the formation and occurrence of rock strata, involving much map work ; palæontology—the study of fossils ; and petrology—the study of rocks both from a mineral and chemical standpoint. This last branch will include the study of minerals themselves, unless a separate mineralogical department is provided. A geological department may comprise the following rooms :—

[1] Further comments on this subject will be found in Chapter V.

Physiography laboratory.	Chemical laboratory.
General geological laboratory.	Rock-cutting room.
Lecture theatre.	Research rooms.
Museum(s).	Dark rooms.
Map-drawing room.	Unpacking and mounting room.
Advanced laboratory (petrology).	Library.
„ „ (palæontology).	Staff rooms.

Physiography Room.—The practical illustrations of natural phenomena in the domain of physical geography and dynamic geology make a most interesting study which lends itself to simple exposition. Hence this work generally forms a part of a junior school course and is often half laboratory half class-room instruction. The effects of rain and rivers in the production of surface features may be investigated by a special form of large shallow tank or sand table, which requires a water supply. **Fig.** 67 illustrates such a table, 12 ft. by 4 ft. and 32 ins. high, manufactured by the Kewaunee Co. of U.S.A., which is lead lined and has a suitable waste pipe. Supplied with the table are moulding trays in which the surface features of the "ground" to be experimented with are modelled in sand. The action of rain, streams, and waves, and the formation of strata of sediment can be readily shown, and the tray then removed so that others can use the table.

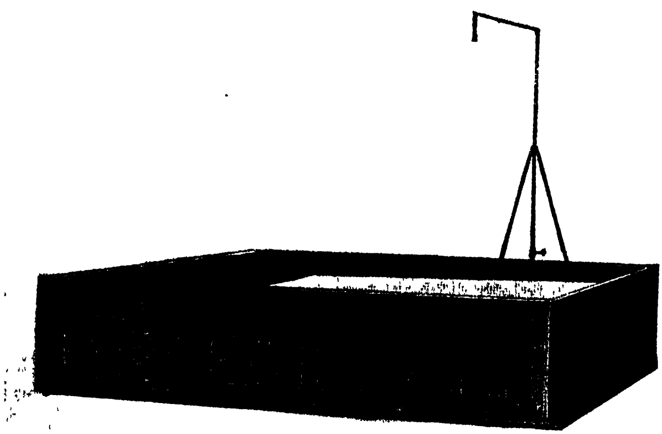


FIG. 67.—Sand Table.

Another feature of this room is a window facing due south with a table or bench immediately under it upon which work demanding the use of a drawing board can be done, and it is important that this window be of plate glass and devoid of unnecessary bars. Maps will be much used for demonstrations, and if large wall maps are employed the simple method of storing them adopted by Mr. L. Brooks, lately responsible for the physiographical

teaching at the William Ellis School, Hampstead, may be recommended. The maps are rolled and hung in a cupboard vertically on hooks from rings at one end. The hooks are placed in the cupboard top diagonally in rows which allows each map to be readily seen and removed. In Mr. Brooks' room each boy has a separate table, 2 ft. 6 ins. high with a flat top, at which work is done on drawing boards. Another feature of his room is a black globe about 2 ft. in diameter, upon which chalk can be used, suspended from the ceiling axially to represent the earth ; the room can be darkened and one of the lights is used to illustrate solar effects with this globe.

In a room for physiography a good deal of cupboard space is necessary, partly for maps and paper but also for simple physical apparatus, and, where geology proper is not separately studied, for common minerals and rocks.

Elementary Laboratory.—The chief work done in this room will be the identification of fossil and rock specimens, in which the use of the microscope, if employed at all, will be very subsidiary. The students should work at small separate tables of ordinary height (about 2 ft. 4 ins.), seated on chairs. In Professor Watts' laboratory at the Imperial College, London, these tables are 3 ft. 3 ins. by 2 ft., and contain one drawer with lock and key, which latter is retained by the student. Good students' collections should be kept in this room in cabinets of drawers which can be removed and carried to the tables for use, and provision may also be made for works of reference. A rather larger table, on a platform 6 or 8 ins. high, is sometimes installed for the demonstrator. As wax has occasionally to be melted and fossils heated (boiled with size, for example), a small fume cupboard with a gas supply is useful in this room which should also contain some spare bench accommodation for putting things down. A water supply is sometimes considered desirable.

Lecture Theatre.—As already stated the general principles which govern the design of lecture rooms are common to all branches of science, and the reader is therefore again referred to the description given in Chapter II. The demands of geology are, however, less than those of most other subjects. Apart from good lantern and diagram arrangements and ordinary lighting, no electric service is necessary, and the provision of gas and water is unusual. No fume cupboard is required; neither need a preparation room be provided in conjunction with the lecture theatre, which, however, may adjoin the laboratory or the museum for convenience in bringing in

specimens. Hence most of the wall behind the lecturer may be devoted to much needed blackboard surface. If the professor's private room or laboratory adjoins the lecture theatre, as at the Imperial College, the lantern slides for lectures will probably be kept in such adjoining room. Most lecturers use large numbers of slides, collections often numbering several thousands. Professor Watts has organized a system of keeping complete sets for various lectures and courses, a duplicate being made if the same slide is required in different sets. This enables a given lecture to be always accessible as a distinct unit. The slides are kept standing upright in nests of labelled drawers without divisions, the sets being provided with index cards.

Mr. J. Allen Howe, a director of the Geological Survey Museum, London, who has been good enough to express his views to the writer, believes in the American plan of placing each slide in an envelope and having them all on open shelves like books, numbered and identified by a card catalogue, with suitable projecting tabs at intervals as guides to location. The wall space occupied by this method is greater, but every slide is immediately visible. Lantern work in geology is less intermittent than in other subjects, hence the location of the lantern at the end of the room among the students instead of on a stand near the lecture table is often considered desirable. By the careful placing of the lights (groups of filament lamps at ceiling level) over the audience and the provision of deep shades, Professor Watts has succeeded in arranging his lecture room so that the switching off of the table lights only, is sufficient, with in daylight the use of dark blinds, to enable a perfectly satisfactory picture to be obtained while the rest of the room is still illuminated so that notes may be taken at the same time. His room also enjoys a remarkable blackboard area, no less than four sliding boards, one in front of the other, made in sections, extending over the whole length of the back wall, are employed. These slide horizontally on rollers and channels like sliding doors.

A remarkable diversity of opinion seems to exist among geologists as to their lecture tables and seating. In the theatre under discussion above, the table, some 21 ft. long, is no less than 3 ft. 11 ins. wide, with an addition of 18 ins. in the form of a flap at the front which can be collapsed. To bring the lecturer nearer his audience, a piece on his side 2 ft. 6 ins. deep and 4 ft. to 5 ft. long is cut out in the centre where a small collapsible reading desk,

specially illuminated, is placed. Raised seating is used for the students, a central gangway being avoided and the front edges of the seats are four inches away from the back edges of the desks and not immediately below them, as is usual in school arrangements. **Fig. 68** gives an illustration, kindly contributed by the architect, M. Nénot, of the geological theatre at the new Sorbonne, which has almost the suggestion of a court of justice, while at the new Sedgwick museum at Cambridge an ordinary table of quite moderate dimensions on a high platform is used, the audience being provided with chairs and small tables placed on a level floor. Professor Marr has, however, informed the author that this arrangement was due to a decision to devote the funds at disposal to the elaboration of other more urgent requirements in connection with the very extensive collections, and that he would have preferred a lecture theatre of the ordinary type had space been available.

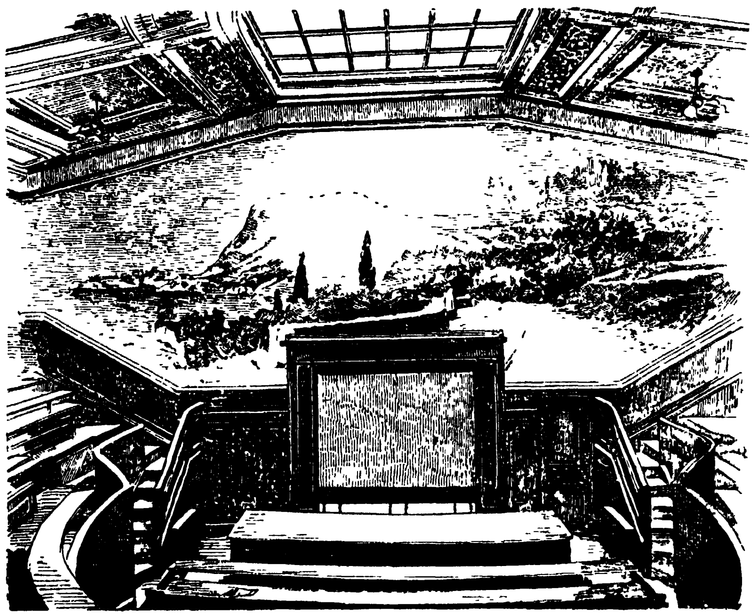


FIG. 68.—Geological Lecture Theatre at the new Sorbonne.

Museums.—The principles of fitting geological museums do not materially differ from those previously indicated. Some of the specimens are, however, of considerable weight and may occasionally need constructional considerations. **Fig. 69** shows a section of one of the cases devoted to the illustration of the mining and use of clays at the Geological Survey Museum, London. The main shelves of these cases are fixed at different angles to provide the best visibility for the adult observer. These cases are about

7 ft. 6 ins. long, and have a pair of doors glazed with plate glass which much assists clear vision.

In a large collection, several separate museums may be required. At

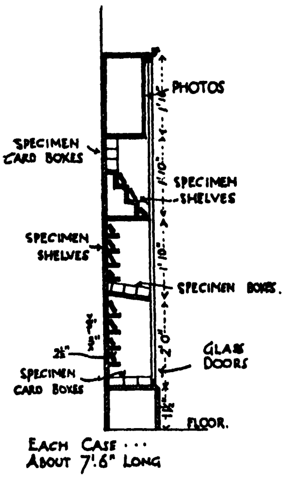


FIG. 69.—Section Through Specimen Cases in Museum of the Geological Survey, London.

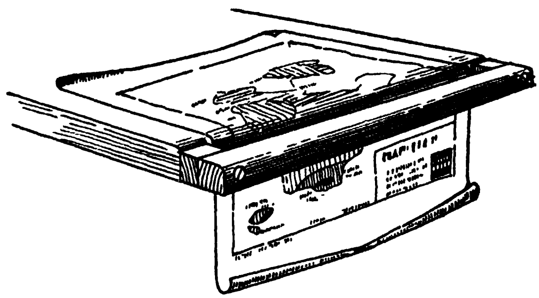


FIG. 70.—Top of Map Table, Geological Department, Imperial College, London.

the Sedgwick Museum, Cambridge, for example, for an inspection of which building the writer has to thank Mr. F. R. C. Reed, there is a palæontological museum arranged stratigraphically, a petrological museum, another for models, and a fourth for the economic applications of geology.

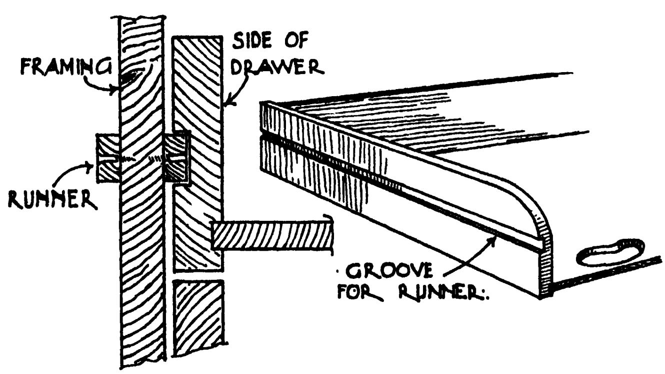


FIG. 71.—Map Trays Showing Runners to Economize Height, Geological Department, Imperial College, London.

Map - Drawing Room.—The study and making of geological maps is so important a branch of geology that a special room is often devoted to this work, and should be arranged like a

drawing office with good north light, the students working at separate tables on drawing boards. The tables used by Prof. Watts at the Imperial College are 3 ft. 4 ins. long, 2 ft. wide, and 3 ft. high. They have a rounded edge in front, before which, attached by strong screws and half-inch distance pieces, is a wooden bar (**Fig. 70**) to prevent maps used for study being damaged by creasing on the table edge. The drawing board is kept on a shelf below the table. The maps are kept in cupboards containing draw-out trays 3 ft. 10 ins. long, 2 ft. 6 ins. wide, and

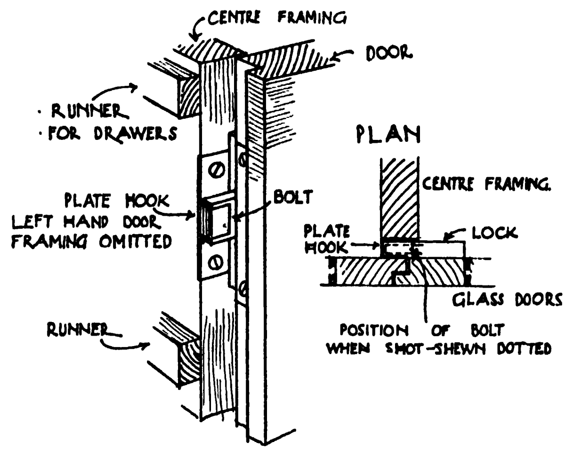


FIG. 72.—Lock to Pair Door Cupboards to Render Bolts Unnecessary, Geological Department, Imperial College, London.

3 ins. high, which slide on runners, and framing between the drawers only exists in the middle of the cupboard, to keep it together (**Fig. 71**). The locks of these cupboards engage with a plate hook on the framing, thus making bolts to the doors unnecessary (**Fig. 72**). Mr. J. Allen Howe, of the Geological Survey Museum, prefers to fold the maps once, or for large sizes into four, when they are cut and backed with linen. They are then stored vertically in cases resembling fittings used for ledgers. **Fig. 73** shows a detail of one of these cases. The

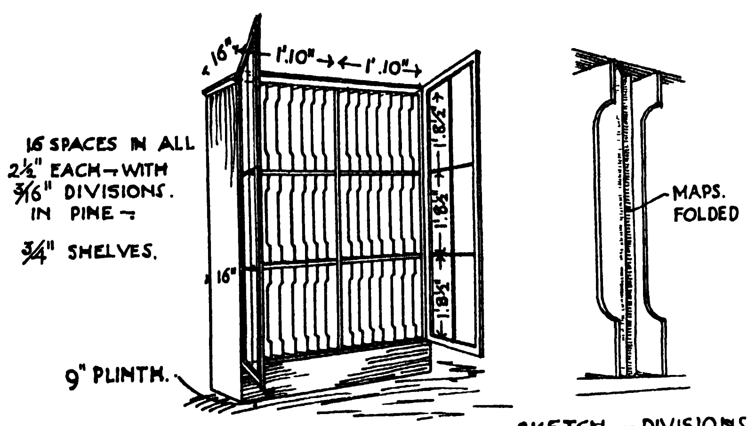


FIG. 73.—Cupboard for Folded Maps, Museum of the Geological Survey, London.

advantage of this scheme is that the maps, many of which are hand-coloured, are not rubbed, and by attached tabs can be at once separately extracted. The expense of the linen mounting, however, is not inconsiderable.

Advanced Laboratory.—An advanced laboratory will probably be devoted largely to petrology or palæontology, and on the assumption that the chemical analysis of rocks and minerals takes place elsewhere, the work in this room will be largely microscopic, hence a steady and ample light is necessary. Benches of a simple character, as described for botany, will be suitable, but in addition, ordinary tables and chairs, for the examination of hand specimens, and for notes, will be found useful. The remarks previously made on the subject of lighting for microscope work, pages 96-97, of course apply equally here. Neither gas nor water is necessary on the benches, though a sink with a supply, and one or two gas jets in some convenient position will probably be appreciated.

As in the elementary laboratory, a considerable number of drawers for students' collections will be wanted, both for specimens and microscope slides. The former should be about 3 ins. deep inside and of such a size that they can be readily carried when full from place to place. Subject to this, they should be as large as possible to reduce the cost and woodwork, and also to save space. At the Imperial College Prof. Watts has standardized all the drawers, the inside dimensions being 1 ft. 10 ins. by 2 ft. by 3¼ ins. deep. This is found to be a little large when rock specimens are in question, these being much heavier on an average than fossils. These drawers should have no glass tops nor divisions, the card or metal trays used for holding the specimens taking the place of the latter. If constructed with runners, as described for the map trays, and without framing, the accommodation for a given height will be increased by perhaps 20 per cent. The use of bass wood or pine for these drawers will reduce their weight and cost. The microscopes at the Imperial College are kept in nests of pigeon-holes 9 ins. by 6 ins. by 16 ins. high, which have glazed doors admitting of immediate oversight. Cabinets for microscope slides which are stored flat in drawers about ¼ in. deep and containing divisions 3 ins. apart require very good cabinet work. The construction of the drawers or trays as a frame with a card bottom glued on appreciably reduces their cost, and almost does away with warping.

Chemical Laboratory.—In the absence of a chemical department

co-operating, a laboratory is desirable for the analysis of minerals and for specific gravity and other determinations. For full analytical work, the fittings for this room will resemble those for a general chemical laboratory described in Chapter II. It may, however, happen that blowpipe work is alone necessary, in which case the provision of gas and one or two sinks with no elaboration of drawers, fume cupboards, or lockers, will be requisite. Prof. Judd designed a table, still in use at the Imperial College, for the blowpipe work of students training as mineral prospectors. These tables measure 2 ft. 10 ins. by 1 ft. 9 ins. and are 2 ft. 7 ins. high. They are designedly devoid of gas and water, the blowpipe work being done by the aid of a vessel of melted wax. At one side, cut in the top, is a hole 14 ins. by 4 ins., below which is a box forming a well in the table 6 ins. deep, in which a set of small reagent bottles and other necessaries are kept. This arrangement has the advantage of allowing the tables to be used for drawing boards when not required for analysis.

Rock-Cutting Room.—A room for the preparation of specimens is essential in a department of any magnitude. Here rock specimens will be trimmed to size in a small machine about 2 ft. square, standing on a very strong table about 2 ft. 6 ins. high. Rock slicing and grinding machines consist of mechanically driven discs rotating on a vertical axis; the former machine is about 2 ft. square and the latter some 18 ins. square. The diameters of the slicing and grinding plates are about 10 ins. They are preferably driven by small motors placed beneath the top of the table supporting the machine as arranged at the Natural History Museum, South Kensington, for an inspection of which arrangement the writer is indebted to Sir L. Fletcher, the late director. At the Imperial College this room is provided with two sinks and a gas supply, and a dust-proof enclosure about 5 ft. by 4 ft. and 7 ft. high, in which is a table shelf for the purpose of mounting slides, which involves the use of varnish.

Mr. Howe lays stress on the necessity for a large room amply equipped with water and good drainage, suitable, for example, for continuous washing away of clay from specimens. The size and fittings of this room will be governed by the inclusion or exclusion of another room for mounting and unpacking.

Research and Dark Rooms.—Geological research in the realm of palæontology is not likely to require any special fittings which have not

been covered in previous descriptions. For petrology, high power microscope work will necessitate good lighting, and some provision in the way of a small glazed cupboard for bottles of liquids of different refractive indices. Other optical instruments of considerable size may be used for special purposes. Dark rooms are chiefly required for goniometer work—measuring the angles between crystal faces—which is best done by artificial light, though a darkened room, into which rays of natural light are admitted, is often used for students. Photographic dark rooms are also required in connection with the preparation of lantern slides, enlargements, and many other recording purposes.

Unpacking and Mounting Rooms.—Unless specimens go direct to the rock-cutting room, a special room for unpacking, determining, sorting, and, where necessary, mounting hand specimens, is required. This should naturally be on the ground level and near an entrance if possible. Here, also, unless storage is provided elsewhere, drawers for duplicates may be arranged, as at least some of such specimens will probably be eventually repacked for transmission without leaving this room.

CHAPTER V.

LABORATORY SERVICES.

GENERAL Considerations.—In this chapter it is proposed to deal shortly with gas, water, electricity, and other supplies, and with ventilation and drainage, as regards their special application to laboratory work. These are essentially engineering matters, and no attempt can be made in a small book of this kind to do more than indicate the general nature of the requirements in a lay manner sufficient to admit of their intelligent consideration in connection with any scheme, leaving to the architect—with, in a large project, such consultative engineering advice as he may deem necessary—the working out of the many problems which must arise, and which are so intimately connected with the construction of his building.

Enough has been said in the preceding chapters to indicate the extent to which the various services are required in the departments of natural science which have been dealt with, hence this subject may be now treated generally.

Gas, water, and electric services naturally enter the building in the basement, where they should be under ready control, and when they are extensive, they should be considered as a whole, otherwise the work of one firm is very likely to render that of another inaccessible. Many pipes, moreover, small in themselves, may require covering and then assume much larger proportions. **Fig. 74** shows the basement pipes in the laboratory of the Institute of Chemistry, Berlin. The grouping of pipes possesses advantages, and if a long central corridor can be ceiled at a lower level than the adjoining rooms, a crawling space may often be obtained in which all main runs of pipes can be placed for the supply of the floor above. Such an arrangement is shown in a section in **Fig. 75.** Control cocks, again, should be brought together, and may be enclosed in a glazed case, so that in an emergency no doubt shall arise as to the location of the main cut-offs. **Fig. 76,** taken from Prof. Beckmann's monograph, shows such an arrangement as used at Leipzig.

All pipes should be visible and exposed on walls, or if architectural considerations render this undesirable in any special situations, they should not

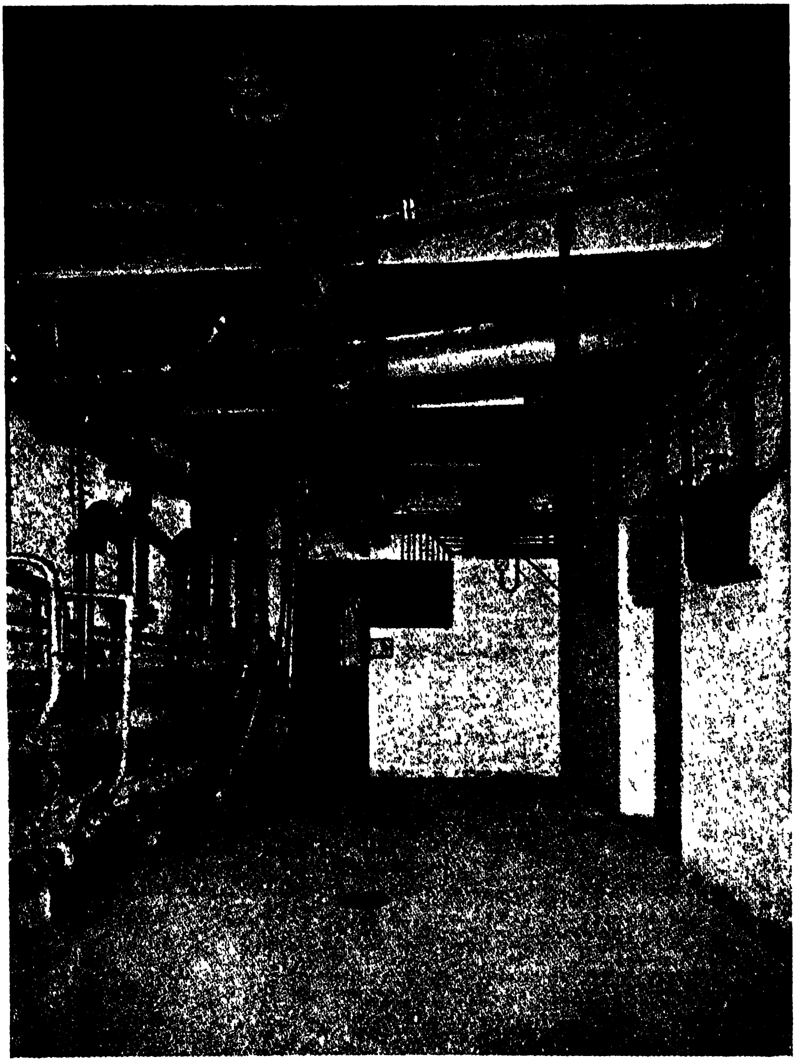


Fig. 74.—Pipe Runs in Basement, Institute of Chemistry, Berlin.

be buried in walls but placed in recesses provided with movable casings in front. A scheme of distinctive colours for the painting of pipes is a great assistance in tracing them, which must frequently be the duty of those not conversant with their arrangement, and, where flow and return differ, as in

the case of electricity and hot water, a further distinction in appearance should be made. The movable heads of different fittings should be of distinctive patterns to avoid mistakes, and this distinction should, if possible, enable fittings to be confidently operated in the dark in emergency.

GAS.

Alternatives to Coal Gas.—Although the use of ordinary coal gas is almost universal, a few words may be said on the provision which can be made in such exceptional circumstances as preclude its employment. Setting aside the production of water gas, oil gas, and the like, which require plant and attendance in some degree commensurate with coal gas on a small scale,

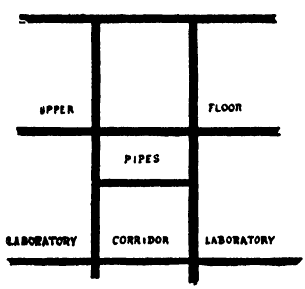


FIG. 75.—Section Showing Pipe Duct over Corridor.

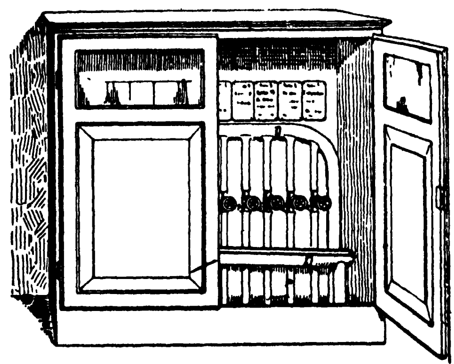


FIG. 76.—Main Cut-offs for Services, Leipzig.

acetylene and petrol gas are the simplest substitutes. The writer's personal experiences of acetylene date back to what was probably the first installation for heating by acetylene in this country, which is still in operation after more than twenty years.[1]

Acetylene requires special Bunsen burners which work under a pressure of 4 or 5 ins. of water. The service pipes may be about half the sectional area of those required for coal gas, and an ordinary bench burner consuming about 1 c. ft. an hour gives a flame of about twice the effectiveness of a coal gas Bunsen consuming the usual 4 to 5 c. ft. The temperature of this flame has advantages and disadvantages ; it enables heating operations to be rapidly performed, and the blowpipe to be frequently dispensed with, and it also involves greater care to avoid breakage of glass through sudden heating.

[1] A small plant erected by The Thorn & Hoddle Acetylene Co., London.

Careful purification of the gas is necessary, otherwise platinum vessels are rapidly spoilt. Petrol gas, which consists of a non-explosive mixture of air with a small percentage of petrol vapour, gives a very hot flame. The plant required for the service of three or four working rooms, for either acetylene or petrol, can be housed in an out-building with a floor area of a hundred square feet or so, and attention, for an average of, say, half an hour a day, by the laboratory or heating plant attendant, is sufficient to maintain the service.

Companies Gas Supply.—Turning to ordinary gas, before formulating any scheme of piping, it is necessary, unless the consumption will be trifling, to figure out roughly the probable maximum demand and then to ascertain the conditions of supply. In large towns where the arterial system is used—gas being made at two or more distant stations, and possibly increased in pressure by valve stations in addition—the mains supply any draw-off point in both directions, but in scattered districts, a single main with a dead end, near which the pressure drops considerably, may alone be available. Since the gas pressure on delivery must not fall below a certain minimum, and is very appreciably affected by the sizes of the pipes to be employed in the building, the calculation of these sizes must be based on a knowledge of the pressure in the mains.

The calculation of gas consumption to be allowed for in a science department is not an easy matter and can only be effected approximately, for not only is the number of burners in use exceedingly variable, but the individual consumption for various classes of work differs considerably.

Estimating Gas Consumption.—Gas companies base consumption calculations on what is known as a "scale light," to which meters are referred, and which is a jet consuming 5 c. ft. per hour. Ordinary bench Bunsen burners, which will always form the bulk of the individual jets in laboratory and lecture work, may be taken as consuming, on an average, 4 c. ft. per hour. It is very unusual to find all the gas cocks provided supplied with Bunsens, or to find those so supplied all in use at one time; hence, for purposes of calculation 50 per cent. of the total number of cocks suitable for Bunsens, reckoned at 4 c. ft. per hour each, will generally give a safe margin for emergencies. This reduction, however, must be applied with discretion to special apparatus, such as ovens and furnaces, which may conceivably all be working at one time and may be individually equal to a dozen or more

scale lights. The consumption at these special points, readily obtainable from the apparatus makers, is a matter upon which the advice of the professorial staff must be obtained.

Gas Pressure.—Gas pressure is measured in terms of the length of a column of water which such pressure will support. This is usually 3 ins. to 5 ins. in the companies mains, and at the jets on the benches this pressure should be $2\frac{1}{2}$ ins. or at least 2 ins. The pressure between mains and jets falls owing to several reasons, but, for gas supplied under these small pressures, the fall may be regarded as depending solely upon the length and size of the pipes, and on their sinuousity and internal condition. In good practice, where round elbows are used, and bends to large radius are employed in place of innumerable elbows and short lengths of pipe, and where T pieces are restricted to the necessities of branches, bends and joints need not be calculated, while if steam pipes be installed for pipes one inch in internal diameter and over, the interior surface conditions need not be regarded as affecting pressure. In first class work, therefore, it is only with the length and diameter of the pipes that calculations need be concerned. There is, however, one other condition that affects pressure in the case of a building of several stories which may be conveniently dealt with here; and this is the height of the jets above the main. Gas is only about half as heavy as air, hence it follows on hydrostatic principles that the higher the jets, the greater will be the gas pressure, every rise of 10 ft. increasing the pressure by about $\frac{1}{10}$ in. This consideration might occasionally render economy in the size of pipes possible on upper floors of lofty buildings. As gas will always tend to rise, the supply should be from below, not from above, but when the latter is necessary, as when pendants are used over tables to avoid making such tables fixtures, pipes might be a size larger than would be necessary for horizontal runs. This method of feeding benches is often useful in physical research laboratories, where the pipes are provided from the ceiling to within 6 ft. to 7 ft. above the floor with one or more elbows, so that they can be doubled up out of the way.

Length and Diameter of Pipes.—As showing the very marked effect of pipe lengths on gas delivered, an illustration from a pamphlet by Mr. Webber[1]

[1] The author has to thank Mr. F. W. Goodenough of the Gas Light and Coke Co. for kindly perusing the proof of this section and for a copy of this brochure, "On the Flow of Gas," by W. H. Y. Webber. John Allen & Co., 8 Bouverie St., E.C.

may be cited. He says a hole in a gasometer 1 inch in diameter would deliver, under pressure of 1 inch of water, 1463 c. ft. per hour, whereas, if a 1 inch[1] diameter pipe 100 ft. long be attached to this hole, the delivery at the end of this pipe will only be 280 c. ft. per hour. Mr. Webber points to practical data which show that the amount of gas discharged from a given pipe is almost directly proportional to the pressure, in spite of formulæ in disagreement with such view. Thus, if the pressure be doubled, the volume of gas discharged, other conditions remaining the same, will be doubled. For very small pressures (a few tenths of an inch) the experimental data he gives show this to be true, but for pressures of more than an inch, the discharge does not increase strictly with the pressure but is less in proportion. Thus 50 ft. of $\frac{1}{2}$ in. pipe under $\frac{1}{10}$ in. pressure are said to discharge $9\frac{1}{3}$ c. ft., and under $\frac{4}{10}$ in. pressure nearly 38 c. ft. but under 6 ins. pressure (60 times $\frac{1}{10}$ in.) only 184 c. ft.

A simple rule often used by gas fitters is that 100 ft. of 1 in. pipe will deliver 100 c. ft. of gas per hour with a loss of $\frac{1}{10}$ in. pressure. The maximum lengths of pipes, which should be used for individual runs, may be taken as follows :—

Internal Diameter.	Length.	Gas delivered in c. ft. per hour under ordinary pressure.
$\frac{1}{2}$ in.	30 ft.	—
$\frac{3}{4}$ in.	50 ft.	—
1 in.	100 ft.	100
$1\frac{1}{4}$ in.	13c ft.	200
$1\frac{1}{2}$ in.	160 ft.	300
2 in.	200 ft.	750
$2\frac{1}{2}$ in.	250 ft.	1,500
3 in.	300 ft.	2,000

In proportioning these pipes to one another, a 1 in. pipe will be suitable to feed two $\frac{3}{4}$ in., six $\frac{1}{2}$ in., or ten $\frac{3}{8}$ in. pipes. The use of pipes of smaller size than $\frac{1}{2}$ in. is not desirable except for very short and preferably vertical runs to single jets, or such as may be necessitated in work on students' benches when taps are placed at the front and jets at the back. The reason for this does not lie in the inability of such pipes when installed to carry sufficient gas supply for single jets, even if of some length, it is that $\frac{1}{4}$ in. and $\frac{3}{8}$ in.

[1] Diameters of pipes referred to are always internal diameters unless otherwise stated.

pipes leave so little licence for deposits of naphthalene and rust, which always gradually encroach on the bore of the tube, that the small saving in cost afforded by the employment of these sizes does not compensate for possible future troubles. Naphthalene is deposited as a fine crystalline powder, and may be readily blown back into the mains, where it again dissolves.

Laying out a Scheme.—All schemes should provide for possible further calls, as it frequently happens that, with every forethought, additional points will be added, and to admit of pressure adjustment to compensate such variations, a governing valve should be placed on each floor which can be set to regulate the pressure after the building is completed. A generous provision of stopcocks, not only to each room, but to each bench or group of jets, should be included so that local repairs or control may be possible without throwing out a large proportion of the service. A great point is often made of having full way cocks and fittings, that is, cocks which, when open, have the same bore as the pipe to which they are attached, but it would appear that, provided the reduction on each side of a fitting is gradual—forming a cone—no detriment results from the actual opening being, within reason, smaller than the pipe, the checking on the supply side resulting in expansion, and thus a corresponding pressure increase on the side nearer the fittings.

In laying out a scheme, plans and sections of the building are, of course, necessary. The consumption at the fittings must first be ascertained and decided for the purpose of calculation, and the piping worked out from these fittings back to the mains on the basis of the drop in pressure allowable to retain a pressure of 2½ ins. at all fittings. If the service is extensive, it is desirable to imitate the arterial system of mains by arranging that gas can be drawn off in more than one direction. This is best done by forming a ring round the basement walls under important floors, and running "risers" (vertical pipes) at several points from it, possibly to further rings on the higher floors.

Occasionally a gas supply is required at higher pressure than that provided by the public mains. If this is necessary, the gas must be compressed by a suitable pump in the building, and, of course, delivered in a separate pipe service. Such a service, however, is not often wanted in an educational institution.

Fittings.—No laboratory fittings should be polished but be bronzed or painted. Small bench jets should have lever taps and tapered nozzles,

suitable for $\frac{1}{4}$ in. rubber tube, and larger fittings may be of the same character. Some form of corrugation on the nozzle is desirable, and the taps should be fixed with washers and nuts capable of operation by a spanner.

WATER.

Water Supply and Pressure.—Water from the public mains is usually supplied through the medium of open tanks placed in the roof of the building and fed automatically by a ball cock. Owing to the greater constancy of supply obtainable nowadays, such tanks are less necessary than was formerly the case. Except for certain delicate washings, for which a low pressure is essential, water is usually required in science buildings at fairly high pressure, and hence a supply direct from the mains is desirable, and, if tanks are installed, and a separate low-pressure system is not called for, they may be used as a "stand by" and be cut off from the supply pipes by special cocks until the water in them is required. If, however, the pressure in the mains is subject to much variation, tanks may be utilized for the general supply, particularly if the building is a high one, for pressure variations are detrimental to the use of filter pumps, and small turbines frequently employed.

Another and quite different use to which tanks may occasionally be put advantageously is for the collection of rain water, which, when filtered, can be employed in the laboratory for certain purposes in place of distilled water.

From the above remarks it will be evident that water pressure is an important factor. This is reckoned in pounds per square inch, and depends upon the height of the surface of the supply above that of the draw-off tap, and such height is known as the "head" of water. Every 2 ft. of head is equal to nearly 1 lb. of pressure per sq. in., hence the pressure of water on various floors of a building and the main pressure in buildings on high and low land are very different. A main supply of 50 lb. pressure in the basement may, for example, give little more than 25 lb. on the 3rd floor of a building. Unless a vacuum service exists in constant operation, this question of pressure is chiefly concerned with filter pumps largely used in all kinds of chemical work. Dr. Tuck of University College, London, who has been good enough to give his opinion to the author, states that these pumps (small glass or metal arrangements attached to the water taps over the sinks) are very inefficient below 40 lb., and, owing to the amount of dissolved air in the water, above 70 lb. pressure, hence 50-60 lb. water pressure should be

aimed at. This is usually unattainable from tanks as involving a head of more than 100 ft. It will not often be found that the public supply is at too great a pressure for use, but it may often be insufficient, in which case artificial compression by a pump must be resorted to if circumstances warrant such an outlay. In large towns, however, hydraulic mains are available, and high-pressure water from this source can be combined with the ordinary supply to give the required pressure by means of a weighted piston working in a cylinder with a cut-off valve which admits hydraulic water only when the pressure falls below a pre-determined amount in the laboratory services. This machine, placed conveniently near the point of water entry to the building, occupies about 4 ft. by 2 ft. on its bed and is some 4 ft. high for a large building. As the hydraulic pressure is great (about 700 lb. in London), a large proportion of water from these mains, which is rated by meter at a higher price than that from the general mains, is not necessary.

Sizes of Pipes.—It is not easy to calculate the necessary pipe sizes for water on a consumption basis, but they must be sufficient to prevent any checking of filter pumps when a good proportion of taps are open. To insure a sufficient supply in a large scheme, a ring main is desirable carried round the basement ceiling and connected to the mains at more than one point if possible, a scheme already suggested as often desirable for gas. From this ring three or four vertical pipes are taken to supply the upper floors, where branches are tapped off to supply the fittings. Vertical "risers," distant from main connections, should be made larger than others to equalize the flow.[1] The use of pipes less than $\frac{1}{2}$ in. diameter is undesirable, as allowance must be made for deposits from the water. In a large scheme, pipes used in the building, may range up to 3 ins. or $3\frac{1}{2}$ ins., while a 1 in. supply will serve many small institutions. Friction during flow has a considerable effect on discharge, and sharp bends and rough unbevelled edges in joints should be avoided. A square elbow is said to be equivalent to the following straight pipe lengths: in $\frac{1}{2}$ in. pipe, 19 ins.; $\frac{3}{4}$ in., 29 ins.; 1 in., 38 ins.; $1\frac{1}{4}$ in., 48 ins.; $1\frac{1}{2}$ in., 57 ins.; 2 in., 76 ins.

Discharge of Water from Pipes.—Though any accurate determination of the delivery from water jets is tedious and complex, it is often useful to obtain an approximate idea of their discharge rate. The following table (in

[1] The consumption in a large department may easily reach 10,000 gallons per week exclusive of boiler and any domestic requirements.

which some decimals are suppressed) is taken from "The Modern Plumber and Sanitary Engineer," Appendix, Vol. 6, 1908, and shows the full bore discharge in gallons per minute :—

Internal Diam. of Pipe.	Head of Water Divided by Length of Pipe.			
	$\frac{1}{100}$	$\frac{1}{10}$	$\frac{1}{2}$	$\frac{1}{1}$
$\frac{3}{8}$ in.	0·22	0·83	2·0	2·9
$\frac{1}{2}$ "	0·46	1·36	4·2	6·0
$\frac{3}{4}$ "	1·33	4·9	11·7	16·9
1 "	2·8	10·2	24·2	35·0
$1\frac{1}{4}$ ins.	5·0	17·9	42·7	61·6
$1\frac{1}{2}$ "	7·9	28·5	67·7	97·7
$1\frac{3}{4}$ "	11·8	42·2	100·0	144·2
2 "	16·6	59·3	140·1	202·0
3 "	47·0	166·0	390·7	562·2

The velocity of water falling freely is, in feet per second, eight times the square root of the height of fall (or head) in feet, or $v = 8\sqrt{h}$, and for average lengths and bends in a building, $\frac{1}{3}$ may be deducted for loss due to friction, giving the following rough table for velocity from jets :—

Head in feet	5	10	15	20	30	40	60	80	100	200
Velocity in ft. per sec.	12	16	20	24	30	34	42	48	54	76

Further information on this subject will be found in a simple form in Clarke's "Tables for Plumbers".[1]

Fittings.—Capstan head fittings are most suitable for water, and, when pressure is not excessive, steep-pitched screw-down valves (sometimes called quarter-turn taps) will save time if in very frequent use. At least some of the nozzles should be elongated, tapered, and corrugated for the attachment of rubber tubes, but very fine jets working under high pressure, if opened rapidly, tend to the breakage of delicate glass vessels.

Water services for laboratory work are almost invariably in steam quality iron pipes. In soft water districts, difficulties may occur through rusting in such pipes, and, unless the expense of copper can be faced, some form of internally applied coating should be considered. In this connection, galvanizing is often resorted to, but is of little permanent use. Any internal treatment, however, requires consideration, as bacteria have been known to

[1] Brought to the author's notice by Mr. Thomerson, Sanitary Engineer of Hackney.

result from the use of certain preparations, a very serious matter in a biological laboratory supply.

If hot water is available it will be much appreciated at one or two points in the large sinks, in each laboratory and in preparation rooms. In American schools a hot water supply is often provided to all the benches. In the absence of any hot water system, a geyser heated by gas will be found useful, and very small sizes suitable for a sink are now made, which are amply served by ½ in. gas and water services. Hot water mains should generally be covered, not only to conserve heat but to prevent heating of adjoining cold supplies, which are necessary for some uses at as low a temperature as possible.

ELECTRICITY.

From the foregoing chapters it will be evident that it is by no means only in a physical laboratory that electricity is needed, and as experimental science develops, this valuable form of energy is more and more called into service, not only for electrical investigations, but for running fans, motors, furnaces, lanterns, pendulums, for chemical analysis, purifications, and like uses. Hence no laboratory is completely equipped in its absence, though the extent of the provision varies very greatly both with funds and professorial ideas.

Nature of Supply.—Generated commercially by dynamos worked by engines operated by steam or gaseous fuel, electricity is conveyed by copper wires in cables covered heavily with insulating material, and, in the best practice, contained in screwed steel tubes. It is produced either as a continuous flow, known as "direct" or "continuous" current, or as a series of rapidly reversed pulsations, known as "alternating" current, measured in "amperes," according to the construction of the dynamo. A large current requires large mains just as a voluminous water supply demands a large pipe.

Another point to be considered in both forms of supply is the pressure or "voltage" employed, which may be regarded as analogous to water pressure. The voltage of a public lighting supply is approximately constant, and may be anything from about 100 to 250 volts. Since most laboratory work requires low voltages, it is often necessary to "transform" the supply. If the current is alternating, this transformation may be effected merely by specially wound coils of insulated wire, known as a "stationary transformer". If direct, either by interposing lengths of special wire to impede the flow,

which is a very wasteful method and only used for trifling and occasional demands, or by causing the supply current to run a motor which is made (usually by attachment to the same shaft) to turn a dynamo, wound to give the voltage required. This machine is known as a "motor transformer". The electric energy is the product of the volts and the amperes, hence, if the voltage is lowered by a transformer, the amperage is increased, and strong currents at low pressure or "head" are obtained. One volt × one ampere = a "watt," which is the unit of electric power at which machines and also lamps are rated.

On the whole, direct current is most useful, and for school work usually alone considered necessary, but for very heavy furnace work, alternating current is essential, and is to be preferred for constant speed motors. One of the chief disadvantages of alternating current is that such supply cannot be used to charge accumulators (described below). When this form of current is alone available, and accumulators are installed, conversion to direct current is necessary by the use of a rotary transformer, a machine somewhat similar to that employed for making a change in voltage.

Accumulators.—The obvious inconvenience of depending upon running machinery at all times for current, and the fact that several different voltages are often necessary, generally leads to the installation of a battery of cells or "set of accumulators".

A general description of a battery or accumulator room has been given on page 90, and, as then stated, a separate room, or for a few cells, an isolated, ventilated enclosure is necessary. In any given battery the cells are all the same size, but several types and sizes are made, those in ordinary use ranging from about 9 ins. by 12 ins. by 12 ins. high to 16 ins. by 14 ins. by 18 ins. high. The cells, usually of glass, should be supported on glass insulators standing in saucers of oil, and may be raised off the floor on well painted, strong, pitch-pine stands. If space restrictions render more than one tier necessary, 3 ft. 6 ins. in height must be allowed in the clear between each row of bearers. The wiring or "cable" taken from the cells should pass out of the room by the shortest route to minimize corrosion.

These cells contain lead plates suspended in dilute sulphuric acid, through which the current is passed. This results in chemical changes which admit of the electric energy being again obtained after any desired interval by connecting apparatus to be operated to the battery by suitable wires. Each

cell has two groups of plates, and when the groups in a single cell are connected externally by a wire, electricity flows through the wire at a pressure of 2 volts, the current depending on the total area of the plates. If one cell is joined to the next and that to the next and so on to form a chain known as connection "in series," the difference of pressure between the free ends of the cells will be the sum of 2 volts per cell. Thus 50 cells so joined would give 100 volts, but if similar plates in all the cells are joined together in the same manner as a group of persons might join, all their right hands together and all their left hands together, called arrangement "in parallel" or "multiple," the effect will be that of one enormous cell, that is, a very great current will be obtained, but only at the pressure of 1 cell, namely, 2 volts. By intermediate arrangement of such 50 cells any voltage between 2 and 100 is attainable. This valuable means of obtaining different voltages and currents is attained by bringing a wire from each group of plates in each cell back to a switchboard upon which the actual linking up of the cells is made, and varied as desired, and from which other wires run to the laboratories.

Cells may be charged direct from any direct current supply, but if, as often happens, the voltage of the supply is appreciably greater than that of the cells when joined in series, this must be reduced through a series of coils of wire, known as a "resistance," which dissipates part of the electricity as heat, or if this involves much waste, by means of a rotary transformer. Even if electricity is specially generated for the laboratories it will probably be required for lighting as well as experimental work, and thus a transformer may still be necessary. Since the sectional area of the copper wires to distribute the supply must be proportional to the current, large currents require cables of considerable dimensions, and the outlay in wiring, even in a building of moderate size, may be heavy. Hence, rooms which require such currents should be as near the plant, particularly the battery and switchboard, as is practicable.

Switchboard.—In a scheme of any size, a switchboard, usually of enamelled slate, will be required close to the machines. To this the main cables will run, and on it will be volt and ampere meters, fuses, and main switches. A second board, best placed in one of the advanced laboratories or under control in some central position, will be required to admit of varied arrangements for distribution all over the building, possibly through the

further medium of one or two sub-boards in other rooms, though concentration on one board is generally desirable. The design of this board is most important, as it forms the heart of the whole scheme. It is to the scheme what a central exchange is to a telephone system, and should admit of a great variety of voltage and current from the supply to the points upon the working benches by changes in its connections.

A Small Scheme.—In a school great variation and power may not, of course, be necessary or justifiable. Possibly 8 or 10 cells of small size will form the battery, housed, perhaps, in a basement lobby—the writer has even utilized a specially arranged window cell. The switchboard will be behind the demonstrator's table in the physical laboratory, and a small enclosed motor generator in the preparation room adjoining. Perhaps current direct from the public mains, but controlled by fuses at the benches and on the board (where a switch will also be supplied), will be laid on round the walls to feed all but the island fittings. The battery wires, say from each pair of cells, will come back to the switchboard where an interchange of connections will be possible, giving large currents at 4 to 20 volts to the benches by another pair of heavier mains from the board. A resistance of wire coils and one of glow lamps may be included and operated from the board to admit of further variation, and the motor transformer will be controlled by a further switch, and may be arranged to give a supply and charge the battery at the same time, if necessary.

As showing the importance attached to electric services in America, it may be mentioned that the regulations for the Boston High Schools require on the lecture tables, current from 2 to 20 volts from 10 cells, and both direct and alternating current at 110 volts up to 30 amperes.

Large Schemes.—In illustration of large schemes two recent examples may be taken, both these are in connection with electro and physical chemistry, which makes the greatest demands on electric service in modern institutions.

Liverpool University. Electro-Chemical Laboratory.[1]

Plans and a description of this building, the electrical arrangements for which were schemed by Prof. Donnan, will be found in Chapter VI. The plant consists of a large 28 kilowatt[2] motor generator converting the public

[1] The illustrations and many of the particulars are taken from "Zeitshrift für Electrochemie".

[2] A kilowatt is 1,000 watts (see p. 130) and is the commercial unit of power.

supply at 230 volts to 80 volts and thus giving 350 amperes, but, by rheostat arrangements, the voltage may be varied between 70 and 120 volts. This machine is used for direct supply and also for charging the battery. Two 5 kilowatt machines of 20 volts giving 250 amperes, the voltage of which can be similarly raised to 40, and which can be run singly or in series or parallel. A single-phase alternator at 80 volts and 1,000 amperes or on another winding 150 volts and 500 amperes with possible reduction to 40 volts. A stationary transformer to bring the alternating current down to 10 volts and thus give 8,000 amperes. Lastly, a battery of 36 large cells, each of about 200 amperes capacity, arranged in 6 groups of 6 cells, each group being further subdivided into subgroups of 2 and 4 cells. An addition of 20 rather smaller cells has recently been made which can be used in series with those already mentioned, giving a very steady voltage of 110. Four main 500 ampere cables run through the building with secondary feeds from them at each floor. The main switchboard, which is of marble on a teak and iron frame, is shown in **Fig. 77**, and the battery switchboard in **Fig. 78**. A special feature of the scheme is the use of bare copper conductors carried on porcelain insulators, these cables having only a coat of varnish to provide against inadvertent short circuit. The wiring on this principle is shown in the illustration of one of the laboratories already described on page 64. The greatest pliability has been aimed at, which is assisted by the exposure of all the wiring, the cost of which was naturally much reduced by the absence of insulated covering, while the current carrying capacity, owing to greater rate of cooling, is thereby increased. There are seventy places in the building for taking current, two pairs of leads make it possible to obtain direct or alternating current at two voltages, and by parallel switching,

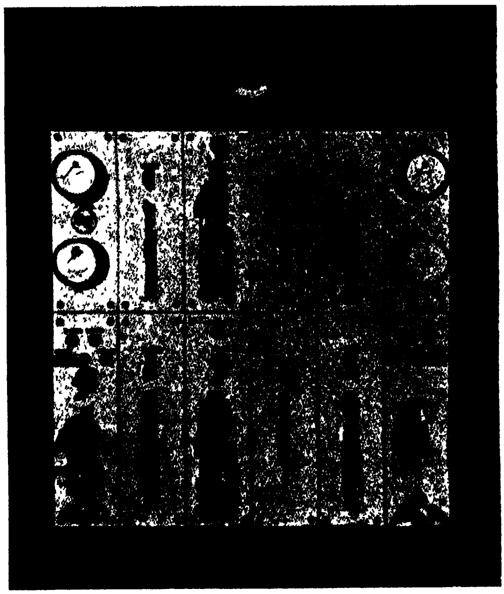


FIG. 77.—Main Switchboard, Electro-chemical Laboratory, Liverpool University.

to take 100 amperes. A 5 ampere supply from the town mains for light and small motor work is also provided. Fig. 79 shows a diagram of the arrangement of the switchboard for individual distribution. This installation cost about £3,000 early in 1900.

Bristol University. Chemical Department.

The scheme for this building, opened at the close of 1910, is due to Prof. McBain and Prof. F. Francis. The plant consists of a motor and dynamo converting 500 volt direct current to 72 volts. The motor has a variable

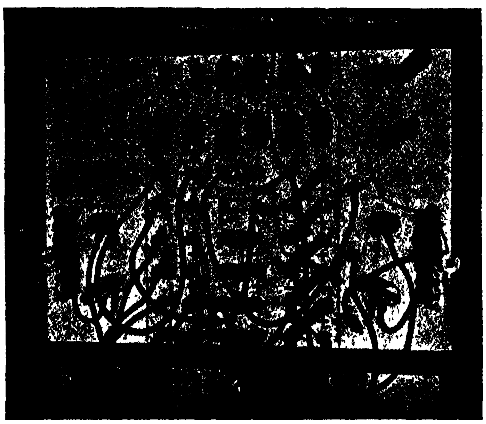


Fig. 78.—Battery Switchboard.

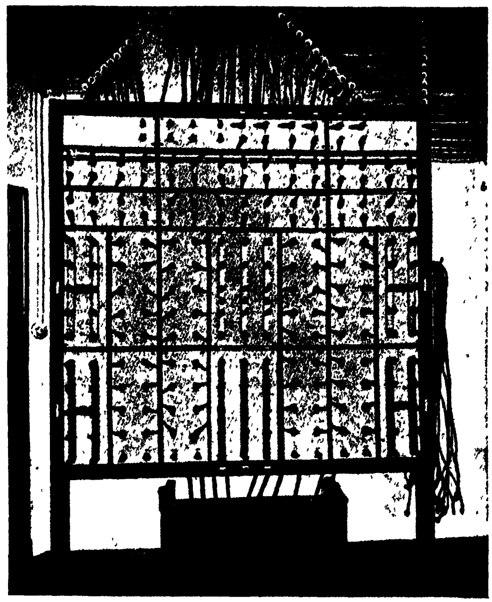


Fig. 79.—Switchboard for Distribution to Benches.

speed and the dynamo can give varying voltages up to 110. A second motor generator is employed for operating the ventilating fans. The battery consists of 72 cells in 12 groups of 6 each, either half can be used for the 72 volt supply, leaving the other half for experimental purposes. There are two further groups, each consisting of 1, 2, and 4 cells, and the connections admit of almost any combination. The battery can produce 150 amperes at 172 volts or 2,100 amperes at 12 volts for 1 hour, and, of course, anything intermediate. The town supply is 105 and 210 volts alternating, and this is available both for lighting and power, in addition to

250 and 500 direct power current. The charging panel of the switchboard is self-contained, and as it is not permanently connected to any source of current is available for the heaviest experimental work, alternate or direct, as required. The distribution switchboard is in the physical chemistry laboratory, directly over the main switchboard, from which each pair of terminals is connected directly to only one point. Sixty pairs of wires run from this board, and these are independent and can be used simultaneously; further, the same pair of wires can be used at different times for currents of either kind at various voltages. This board also has six trunk cables leading to the main board by which direct connection from the town mains, motor transformer, or battery can be obtained. The supply on the distribution board is through bus bars.

STEAM.

A steam supply is very unusual in schools, but might be justified when exceptional facilities exist for its installation, as, for instance, close proximity to exhaust steam from the power plant for the building. In institutions for higher work, however, more especially for organic chemistry and physical experiments on heat, it is very desirable. Steam is usually supplied from a special boiler and often at two different pressures in separate service pipes, for which, however, the same boiler may be used if fired to give the higher pressure, and provided with a reducing valve to the system designed for the lower pressure. The chief use of high-pressure steam, at say, 30 to 50 lb., is for heating drying ovens and similar apparatus in more or less continuous use, while low-pressure steam at 5 to 10 lb. is suitable for individual bench use for distillations, evaporations, and the like. The actual supply by no means increases in proportion to the pressure, for example, under 1 lb. pressure 20 ft. of inch pipe will deliver about 2 lb. of steam per minute, under 10 lb. pressure, 2½ lb., and under 50 lb. pressure, 4 lb., with a loss of 1 lb. pressure in each case.[1] Steam, like coal gas, is about half the weight of air, bulk for bulk, hence its pressure is to some extent affected by altitude. Steam velocity suffers considerable loss in small pipes, due to friction, but, since loss of heat in large pipes, due to radiation, produces very serious condensation, large pipes are never used for distribution, 1 in. and ¾ in. pipes being usual. Sharp bends further check the supply, and to give

[1] "Steam Pipes," M. H. Booth, 1905.

an idea of their effect, an elbow in $\frac{3}{4}$ in., 1 in., and $1\frac{1}{2}$ in. pipes are said to be respectively equivalent to an increased length of 14, 16, and 22 inches in such pipes.[1]

Horizontal runs should be avoided as far as possible, but in any event the whole system should be laid to admit of complete drainage to the lowest point, and separators (valves to pass condensed water while not ejecting steam) should be provided. The main feature of the scheme should be a series of vertical pipes taken up on the main walls through the several stories, with separators at the bottom of each, and if the cocks for use can be confined to wall benches near these vertical pipes the system will be much simplified.

Steam pipes should always be covered with non-conducting material, as, at best, conduction is considerable, especially with the intermittent and local use generally experienced in laboratories. To give an idea of the effect of covering; a bare iron pipe 2 ins. in external diameter will, at ordinary room temperature, lose some 219 heat units[2] per hour for every foot in length. An inch covering of felt will reduce this to 44 units, and if 2 ins. thick, to 28 units; these figures are for steam at 75 lb. pressure.[3] Felt, however, like other combustible coverings, is not desirable, and "Fossil meal," which is diatomaceous earth applied as a paste, is largely used. Efficiency depends more upon the cellular structure of the covering than on its composition. All coverings radiate heat, and such loss by radiation naturally increases with the area of the surface of the covering, hence great thickness is not effective, and in good work this is usually about $1\frac{1}{2}$ ins.

Part of the condensed steam—usually from the ovens of the chemical laboratory—is often collected for laboratory use as distilled water, and this condensation may be purposely increased by allowing the steam after use to impinge on a metal surface cooled on the other side by running water. Other condensed steam should be returned to the boiler.

COMPRESSED AIR AND VACUUM SERVICES.

A compressed air service is useful in a laboratory for the aeration of water, often necessary in biological work, for passing air currents through apparatus for drying, for combustions, and other special uses, but this provision is seldom found except in large institutions. Similarly a

[1] "Steam Pipes," M. H. Booth, 1905.

[2] British Thermal Unit, B.T.U., heat required to raise 1 lb. water 1° F.

[3] "Steam," Babcock & Wilcox.

vacuum service is useful for filtrations in place of water, and for drawing gases over materials under experiment. These services are supplied by very similar machines, in fact many compressors may be run as exhausters. The difference in pressure obtainable by the use of centrifugal fans is only measurable in ounces, and for the purposes in question, either a rotary blower or exhauster or a piston machine (a pump) must be used. The pressure limit of the former is about 12 lb., above which the latter form of machine must be used. Compression or exhaustion can also be effected by running water on the principle of an ordinary bench filter pump, without moving machinery, but this method is usually much too costly to be considered for a general supply service. In order to equalize the pressure in the service pipes and prevent the pulsations of the machine being felt at the fittings, some form of storage cylinder is necessary between the machine and the main supply pipes, and this is generally placed close to the machine itself. Further, automatic regulators are sometimes added which start and stop the pump when the pressure passes beyond the range of certain pre-determined limits, which, of course, effect a great economy in power and attendance. A small basement room, such as has been described for a liquid air plant, is usually amply large enough for the plant for either of these services. As to the power required, for the smaller sizes, about 1 horse-power is necessary for each 1,000 c. ft. of air dealt with. The service pipes themselves are not large. At the machine these may not exceed $1\frac{1}{2}$ ins. in diameter unless the system is extensive, while $\frac{1}{2}$ in. pipes to the fittings are usually ample. In selecting the actual taps for the fittings it should be remembered that ordinary rubber tube will not be used, but thick walled pressure tube, the bore of which may be less than $\frac{1}{8}$ in., hence special jets of very small diameter are requisite.

VENTILATION.

The general subject of ventilation is beyond the scope of this book, but some reference to the special needs of laboratories is necessary. Owing to the noxious gases evolved in certain work, the extent of which has been indicated for different subjects by the provision of fume cupboards enjoined, natural ventilation by windows and chimneys is insufficient and special arrangements are necessary for carrying off these gases. Fume cupboards, combustion hoods, and chemical lecture tables all require special flues, which are generally operated either by electric exhaust fans or draught caused by gas jets.

Ventilation by Fans.—When fans are used all the flues may be combined and operated by one fan which is best confined to this duty but is sometimes responsible for general ventilation of rooms in addition, or each flue or group of flues may have its own fan. For the continuous work of a large department making heavy calls on special ventilation probably the single central fan system is the better.

Fans are of two types, centrifugal and disc fans. The former are constructed on the principle of a paddle wheel, and on rotation, throw the air towards the circumference, thus creating a partial vacuum near their axes which causes a flow of air. The latter resemble ships' propellers but have, however, usually more blades, and the air in this case is "screwed along" parallel to the axis of the fan. Centrifugal fans are necessary where appreciable resistance to the movement of air exists, which is the case when systems of flues and trunking are involved, and the most efficient types are said to be those which possess a large number of small vanes (paddles) near the periphery, being light in weight and requiring the least power. Ranging from about 2 ft. 6 ins. to 5 ft. in diameter,[1] with respective speeds of say 350 and 200 revolutions per minute, the rated discharge of the former size may be roughly 3,500 and of the latter 15,000 c. ft. per minute for working in free air, which are said to be reduced to about 2,500 c. ft. and 11,000 c. ft. per minute respectively when these fans are attached to average systems of trunking. Where direct current is available, these fans should be driven by a direct coupled motor which is more silent and compact than belt driving, the motor, of course, being placed outside the fan casing which takes the form of a partial volute. This enlargement of the casing towards the free opening is necessary to prevent loss of efficiency by pressure from the expelled air. An illustration of this type of fan, as installed at Leipzig University, is given in **Fig. 80.** Centrifugal fans are also used as blowers when large volumes of air at low pressure are required, as for blast furnaces.

Disc fans are most suitable for use in free air, as, for instance, in a wall opening where air from a cupboard or hood is to be discharged freely into the atmosphere outside. They are usually smaller, lighter, simpler to fix and less costly than centrifugal fans. Disc fans are also often used for simple duct systems of no great length and of efficient size, and for cases in which the velocity of the air is not to be more than 600 ft. to 800 ft. per minute, Mr.

[1] For a few rooms smaller fans down to possibly 15 ins. diameter are often sufficient.

Hubbard[1] gives the following simple rule for finding the extraction of disc fans. Multiply the diameter of the fan in feet by its area in square feet and by the number of revolutions per minute and the result by 0·7 (or roughly, take ¾ of the result) which will be the number of cubic feet of air discharged per minute. Fans may, of course, be run by other sources of power than electricity, but no other source is, in practice, applicable to a number of small fans.

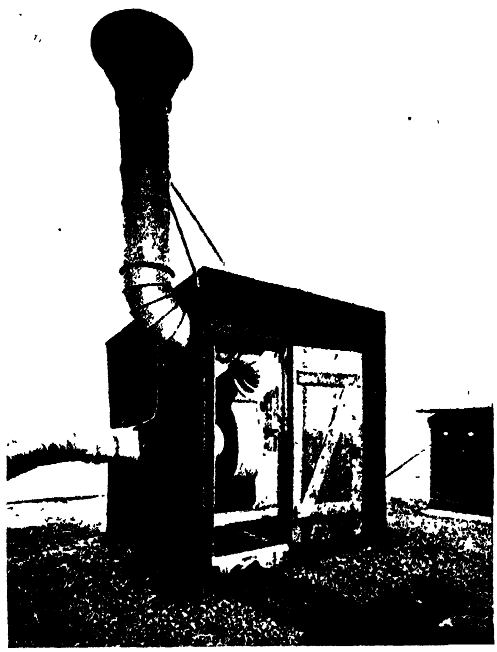


FIG. 80.—Ventilator Fan, Leipzig.

Ventilation by Gas.—The use of gas jets for ventilation depends upon the production of a column of hot air in the flue, which, being lighter than cold air, tends to rise. Apart from the exceptional conditions in which the flues are combined with a chimney shaft, the movement of air in which is maintained by furnace gases, each flue requires a separate gas jet at its junction with the fitting to be ventilated. Experiments seem to have shown that the placing of bodies over the flame to absorb and distribute the heat is not effective, and that it makes no difference whether the flame is luminous or burnt mixed with air. Usually a Bunsen is employed, but of a more powerful type than those used on students' benches. It is impossible to give the consumption necessary for efficient ventilation, which depends on the length, directness, and size of the flue, and also on the air temperature. In winter, owing to the warmer air in the building, flues will often work with very small jets, but the gas piping for each flue should be arranged in anticipation of, say, 20 c. ft. per hour. Metal soon corrodes in these flues, and porcelain burners are to be recommended, but corrosion of metal burners may be much reduced by placing them below the actual mouth of the flue itself, and by frequent painting. The use of gas has the advantage of

[1] "Power, Heating and Ventilation," Part II., C. L. Hubbard, U.S.A., 1914.

allowing each fitting to be ventilated only when in use, and also saves much complex trunking, though it may involve thicker wall piers. It will be found in practice, however, that if gas is to be economized, it must be capable of being readily lighted, extinguished, and observed.

Construction of Flues.—Flues may be built in walls, or formed of glazed drain pipes, sheet metal, or wood. The first form is almost invariably used in this country for ventilation by gas, though in Germany the very unsightly glazed pipes on the wall face are common. For a small fan system, sheet steel pipes, preferably circular in section, and lead coated[1] should be used, but when the main trunks are necessarily large, these may be of brickwork, hollow terra-cotta blocks covered with cement, or of wood, though the use of a combustible material in a position hardly likely to lead to frequent inspection, is questionable for this purpose. Smoothness and the absence of sharp bends has a very considerable effect in aiding efficient draught. The general principle to be adopted in arranging a flue system is to provide a trunk section throughout, of progressively increasing sectional area in the direction of the draught, equal in area to the sum of the branches opening into the various fittings behind it. For example, if a 4 in. diameter ($12\frac{1}{2}$ sq. ins. in sectional area) opening to a fume cupboard is attached to a trunk, on the entrance of another 4 in. flue, the trunk sectional area should increase from $12\frac{1}{2}$ to 25 sq. ins. and acquire subsequent enlargements equal to the sectional area of every branch picked up. The same rule, of course, applies to the junction of any branch trunks into the main trunk. This means that in a large system, the main trunk may become a very appreciable constructional item, possibly four or more feet square. If the trunks are of metal or wood, and of large size, stays, either internal or external, are necessary to give sufficient rigidity, more particularly if a tubular form is not adopted, and the gauge of metal used must also be governed by size of the trunk. For a rectangular flue 12 ins. by 10 ins., sheet steel $\frac{1}{64}$ of an inch thick weighing 10 ozs. to the sq. ft. is suitable. Bends in sheet iron flues should be what is known as "lobster back," or, better, in sections beaten to shape and riveted, all sharp elbows being avoided, and junctions should not be at right angles but enter acutely in the direction of the air current. If the length of horizontal flues is very great, the sectional area should increase

[1] Circular trunks are cheaper than rectangular ones in most circumstances. The lead coating is obtained by a process similar to galvanizing, but is more costly.

slightly more than that of the sum of the flues picked up, because such lengths have no natural up-draught. All suction of air in a downward direction should be avoided if possible as the exhausted gases are invariably warm, but if this is necessary owing to the main trunk being in the basement, a still greater area allowance should be made. No system can be apportioned with such accuracy as to provide for every variable factor, for which reason some means of adjusting the draught in different branches after the laboratory is in use is very desirable. This may be effected either by sliding doors similar to dampers in kitchen flues, or by pivoted discs fixed in the flues and capable of rotation on a central axis so that they can be placed to practically close the flue or in any intermediate position until, with their edges in the direction of the current they offer no appreciable resistance (**Fig. 81**). Means should be provided for permanently fixing any such adjusters when a satisfactory condition of equality between the draught in the different branches has been obtained by trial.

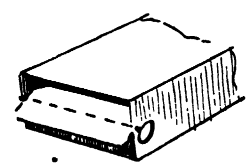


FIG. 81.—Draught Adjuster in Flue.

The smaller and longer the flues and the sharper and more numerous the bends, the greater is the frictional resistance, and since this increases very nearly in proportion to the square of the velocity of the air current at high speeds, a low velocity will prove an aid to efficiency. Sheet metal ducts are usually soldered and made in lengths which are subsequently fitted together, but large sizes should be riveted. A coating of hot pitch should be applied internally, and some means of access at a few convenient points for renewing this coating is desirable though perhaps seldom provided.

Flues for Gas Jets.—Single flues for individual fittings operated by gas are generally built in walls and terminate with chimney pots. These flues are best made with 6 in. or 9 in. circular pipes which obviate the necessity for much supervision required during building to insure freedom from roughness and obstructions common in rectangular brick lined flues. What has been said in reference to bends applies, of course, to such flues, but to prevent entrance of rain and reduce down-draught, one or more gradual bends are desirable. Long flues may require 12 in. diameter pipes. Subject to difference in frictional resistance, a long vertical flue will be slower to start working, but more efficient when well started, than a short one.

The internal terminations of these flues require care. Condensed vapours

are liable to occasionally drip from them, hence their mouths in the fittings should not be over areas likely to be used for apparatus. To meet this, the openings are often in the walls of the cupboards and not in the tops, the glazed bricks or tiles, usually covering the walls, being continued into the opening to ensure cleanliness. Sometimes the flue is continued to near the bottom of the cupboard where a small hole for conveying noxious gas given from a tube of some apparatus is provided. The passing of such tube into the flue itself insures a much better atmosphere in the cupboard, but such an operation is not practicable in most experiments.

A flat double roof with perforations, used for the fume cupboards in the Cambridge University chemical laboratories, which takes the place of the ordinary flue opening, has been referred to on page 38.

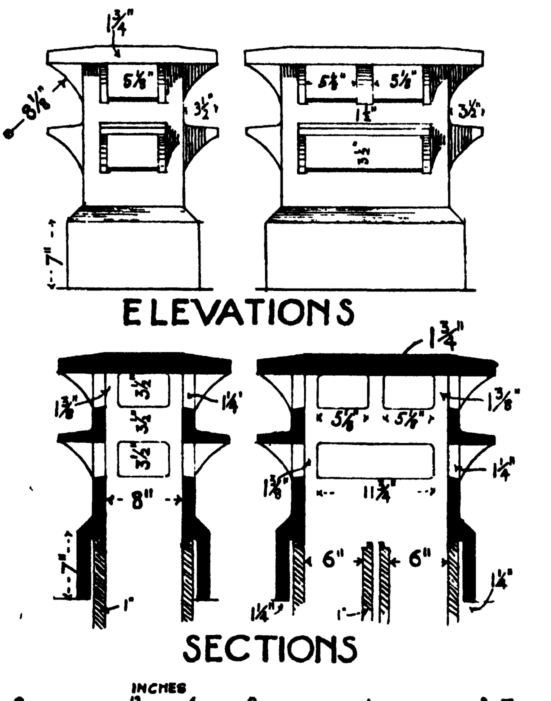


FIG. 82.—Detail of Flue Exits, Chemical Institute, Berlin.

Flue Exit Pots. — Flue exits into the open air, more particularly those from individual gas flues which have no great power behind them, require placing so that winds in certain directions will not cause down-draughts. If a vertical outlet be placed in a wall, when wind blows against this wall, down-draught is exceedingly likely. Open chimney pots, owing to higher surroundings or other more obscure causes, sometimes fail in a similar manner. Much attention has been paid to this subject at Fischer's laboratory in Berlin. The special pots used at this institution, with their dimensions, which are important, are shown in **Fig. 82.** This pattern has been adopted by Prof. Simpson at the University College, London.

DRAINS.

Laboratory drains differ widely from house drains, and although local sanitary authorities without experience in these matters sometimes seek to impose upon science buildings regulations in every way proper to house drainage, some of these requirements (particularly in the matter of traps) are not applicable. Ready accessibility is a first essential, hence long lengths of drain, except where vertical or at such high angles as to make this impossible, should not be formed of enclosed pipes but channels with movable covers.

Wastes from Fittings.—From the actual fittings, the short lengths of drain necessary for discharges to floor channels are usually either of lead 1 in. to $1\frac{1}{4}$ ins. in diameter[1] or in stoneware pipes 2 ins. to 3 ins. in diameter. These pipes should not be trapped. The amount of corrosion which takes place in lead pipes—especially when vertical—is exceedingly small, and they are more compact and readily fitted than sanitary pipes, which are only made in lengths of from 2 ft. to 3 ft., and have walls about $\frac{1}{2}$ in. thick, which allowance must be doubled for the collars at each junction. Such pipes are often jointed in a mixture of Stockholm tar and fireclay, which can be obtained from chemical plant contractors. These wastes usually require some support by wood framing or hinged iron holderbats (holdfasts) and should end 2 ins. or 3 ins. above the channel, into which they discharge to clear the flow from other fittings. Further, a slight bend to make the opening face the direction of the flow is desirable to prevent local overflow, or the vertical deposit of any solid matter (**Fig. 83**). This is readily arranged with lead pipes.

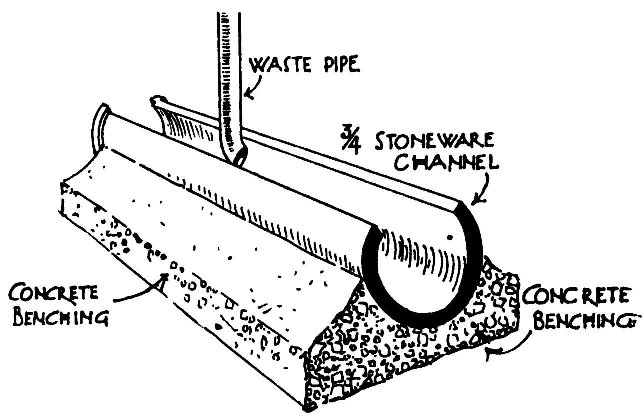


FIG. 83.—Waste and Drain to Laboratory Benches.

Channel Drains.—Drainage channels may be made of lead or asphalt.

[1] "Diameter" always refers to internal diameter unless otherwise stated.

on a suitable foundation but are generally either of glazed ware or wood covered with pitch. Opinions are sharply or fairly evenly divided as to the desirability of the two last-mentioned forms. Glazed ware channels have numerous joints, are more costly, and usually require more constructional considerations but less periodical attention, while treated wood can be made in long lengths, but wants re-coating from time to time, and must thus be everywhere accessible. Glazed channels are made in a great variety of forms, 4, 5, 6, 9, and 12 ins. in diameter, in lengths up to 3 ft., and also in appropriate bends, junctions, and taper pieces. The usual forms are half channels (semi-circular in section), three-quarter channels, and troughs (half channels inside and rectangular outside). "Benched" channels, in which one side is continued on the curve higher than the other for flow round corners, are also made.

One of the essentials for successful use of these pipes depends upon their support upon material not likely to move. When placed in the centre of benches, they should rest on brick and cement, or be placed in solid floors and should not be supported by the bench framing. Raised slightly above the floor they are more accessible from the ends and locker backs of the fittings than when sunk in the floors. No perfect jointing material capable of resisting all organic liquids which find their way down sinks has yet been discovered. Probably the best plan is to joint and bed the pipes in strong portland cement mortar, rake the joints well out before the mortar sets, and, when set, fill the joints thoroughly with bitumen worked in and smoothed with a hot iron. When sinks are only necessary at the ends of benches, as, for example, in double chemical benches accommodating four students, no drains in the benches are necessary, and this condition should always be aimed at.

Channels in Upper Floors.—Difficulties often occur in taking drainage through suspended floors to the outer walls, and unless a double floor—certainly the simplest solution—is provided, it is usually essential to design the drainage in relation to the floor construction in order to reconcile it with steel joists or concrete beams. Some fall must be given to the drains, and as many modern floors, apart from their surface coverings, are not more than 6 or 8 ins. in thickness, drainage lines in such cases may govern the constructional floor members, which must be parallel to, or at least not across, such lines. There are so many factors varying with each building that

generalizations are impossible, but one instance may be cited as showing the ingenious way this problem, in a single thin floor, has been solved in a recent laboratory,[1] the plan of which is shown on page 154. In this case it was impossible to take a single line of drainage through the floor from the most distant sinks to the wall outflow while providing a suitable fall. The floor of the general laboratory is supported near its centre by a cross wall below, on the top of which is a central drainage channel fed by shallower branches from the fittings at both ends of the room. The steel work (in this case steel

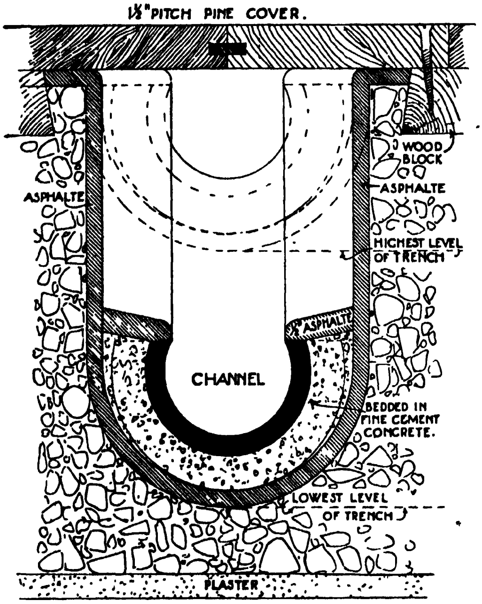


FIG. 84.—Floor Drainage, Harrow School Chemical Laboratory.

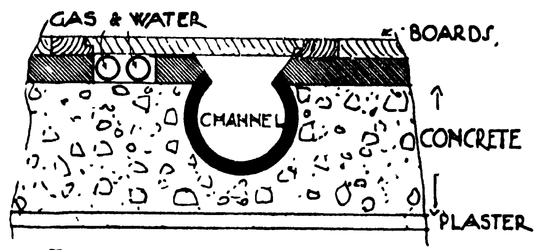


FIG. 85.—Movable Cover to Floor Drain and Services.

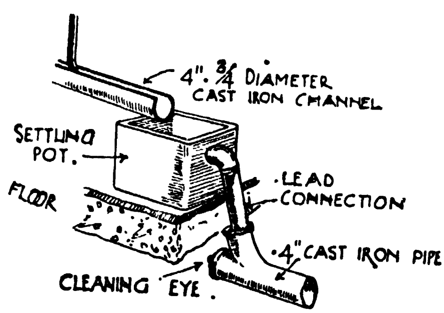


FIG. 86.—Settling Pot and Connection to Drain slung on Ceiling.

reinforcing rods) takes a bearing on this wall and is depressed into the cornices of the rooms below, thus giving room for the drain on this wall at right angles to the direction of the steel reinforcements. From this a branch at right angles, parallel to the reinforcements, runs to the outside wall reaching the ceiling level on its under side at the wall exit ; a good fall of 8 ins., being about 1 in 82, is thus obtained. Fig. 84 shows a section of the architect's channels, which have a complete external layer of asphalt, in

[1] Chemical Laboratory, Harrow School, designed by Mr. Osborne Smith, F.R.I.B.A.

which the glazed pipes are subsequently bedded in cement and then benched with asphalt on each side. A rebated frame and cover is often provided for floor drains, which may conveniently enclose also gas and water services if these have, as is usual, to cross floors (**Fig. 85**).

As to the size of these channels, a 4 in. three-quarter channel is usually sufficient, but if the system is extensive, or it is anticipated that large washing up sinks will be discharged when nearly full and without the use of grids, a 6 in. channel will be desirable for the main trunks, but as such sinks will be usually on outside walls, they may often be arranged to discharge directly into the outfall, instead of into the floor channels. This outfall is usually a large open head attached to a heavy and well-tarred iron pipe, for the drains of upper floors.

Cases often occur, especially where drainage has to be contrived in existing

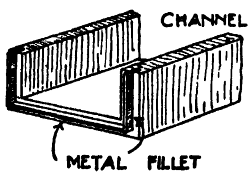


Fig. 87.—Iron Tongue at Straight Junction in Wood Drain.

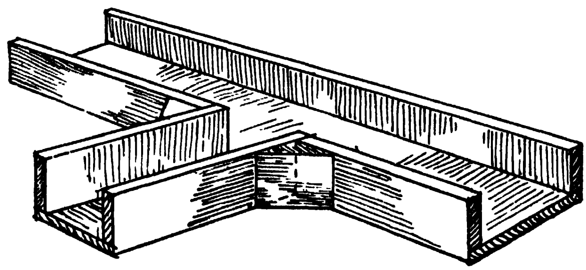


Fig. 88.—Cross Junction in Wood Drain.

buildings, in which it is quite impossible to take the drainage out in the thickness of the floor. In such instances, 3 in. or 4 in. heavy iron pipes (which are made in 9 ft. lengths) with elbows jointed in "blue lead" (metallic lead) cut through the floors, may be suspended from the ceilings below. A piece of lead pipe may be used to make a suitable connection with the working bench drains in such cases and this will be assisted by the interposition of a settling pot, further referred to on page 148. A cleaning eye is desirable at the upper end of the ceiling pipe. **Fig. 86** shows the arrangement suggested. If painted to match the ceiling, such pipes are much less of an eyesore than might be expected, and can, of course, be encased as beams, though best left exposed.

Wood Channels.—Wooden channels are usually either rectangular or V shaped in section. They can be made in lengths equal to the length of boards obtainable, say, 12 ft. to 16 ft. If rectangular, 3 ins. by 3 ins. intern-

ally is sufficient for small branches, main trunks increasing possibly to 5 ins. by 5 ins. Junctions are often placed at right angles, but are better, though less easy to connect, splayed, to follow the current. These channels must not be placed in the ground, nor should they be bedded in concrete, but supported on wood bracketings with free air round them to avoid the possibility of rotting. They may be made of any wood—deal or pine is quite suitable—which must be well seasoned and about 1 inch thick. Though sometimes grooved and tongued together, straight jointed boards, strongly and carefully nailed, are really as good, given an efficient covering. Junctions in straight lengths of channel are best made with iron tongues. The ends of the boards should be grooved and well covered with pitch, after which the tongue, carefully bent to fit, is driven well home into one section and the other side then driven into it when the bed and bearing is ready so that the joint need not be afterwards disturbed (**Fig. 87**).

The use of tongues for right angle and splayed junctions requires great care, as the groove is then across the grain of the wood, which is apt to split, and probably butt (flat) joints nailed together after the faces have been well covered with hot pitch are the best, strength being added by the use of external angle blocks (**Fig. 88**).

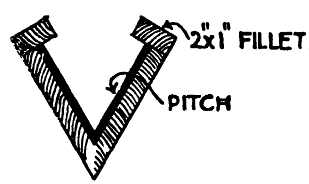


Fig. 89.—V-Shaped Wood Drains as Used in Benches.

A description of the drainage on this system at the Cass Institute, London, appears on page 165, and should be referred to as an example of the most successful use of these drains. Wood drains are also often found above floor level in the fittings, in which case the V shape is probably most common. They have been used, for example, in the new chemical department at Bristol University, where, in benches 9 ft. long, with two sinks, they are about 4 ins. in vertical depth and about the same width at the top internally. As in the instance cited, small fillets are often placed at the top to increase the capacity and to allow for splashing (**Fig. 89**). The V form has advantages in the matter of discharge to lower levels at the end of the bench. At Bristol, these channels are movable and are drawn out through doors at the ends of the benches for annual re-pitching, a very desirable arrangement.

Coating Wood Drains.—The proper composition of material for covering wood drains has yet to be determined, and all that can be said is that some bituminous substance which retains a certain amount of pliability

when solid is necessary to allow for inevitable changes in the wood due to atmospheric influences. Thus coal-tar pitch, which becomes brittle, is not suitable. Probably natural bitumen—the quality of which may be gauged by the percentage soluble in chloroform—is, as far as is known, most suitable. This contains volatile and low melting-point constituents, which admit of its application as a liquid, and also bodies which, on exposure, oxidise and perhaps polymerize, forming insoluble resinous solids. The wood drains should be put together with hot bitumen on their jointed surfaces, then be given a good coat applied hot at the shop, and a further heavy coat melted down with a blast lamp to form a complete, and finally, hard, almost glossy surface after fixing (including all arrangement of junctions and branches) is finished.

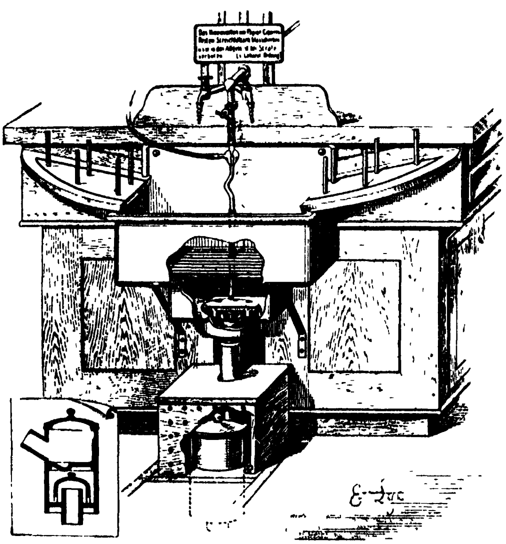


Fig. 90.—Settling Pots at Leipzig.

Lead Channels.—If lead is used for laboratory drainage channels, it must, of course, be suitably supported by wood, and, provided solder is avoided [1] and due allowance made for expansion, by using drips where long lengths are required, it makes a very satisfactory material. The corrosion, if care be taken to avoid pouring strong nitric acid on to it—and strong acids should never be emptied into any drain—is quite trifling. A detail showing such use of lead has been given on page 33. The best milled lead weighing 6 or 7 lbs. to the sq. ft. should be employed.

Settling Pots.—Opinions differ as to the use of settling pots or gulley traps in laboratory drainage for the purpose of catching material which should not find its way into the drains external to the building. Where there are no drains in the fittings, and all sinks contain grids which cannot be readily removed by the students, they are hardly necessary, except for the purpose of recovering mercury, for which provision may be made at the main channel exit or exits from the laboratory, but where a sudden drop is necessary, as

[1] "Burnt" joints, i.e. made by fusing the edges of the lead itself together, should be used.

often occurs at the end of bench drainage, some enlargement for the cascade is required and a settled pot meets the difficulty. Usually of earthenware, 10 ins. to 12 ins. square inside and the same depth, but sometimes cylindrical, these pots have spouts well below the top, the sectional area of which should exceed the sum of the areas of the sink wastes or grids, if provided, behind it, to allow for their slight discharge head. The discharging spout is sometimes carried down as part of the earthenware inside the pot to prevent floating bodies passing on to the drains, but unless the diameter is really maintained in this pipe, probably some form of vertical grid is less likely to give trouble, and this should be placed portcullis-like across the pot. Very small lead tube reinforced by iron wire threaded through it, and then closed at each end, woven to a coarse mesh, might prove a simple and effective grid.

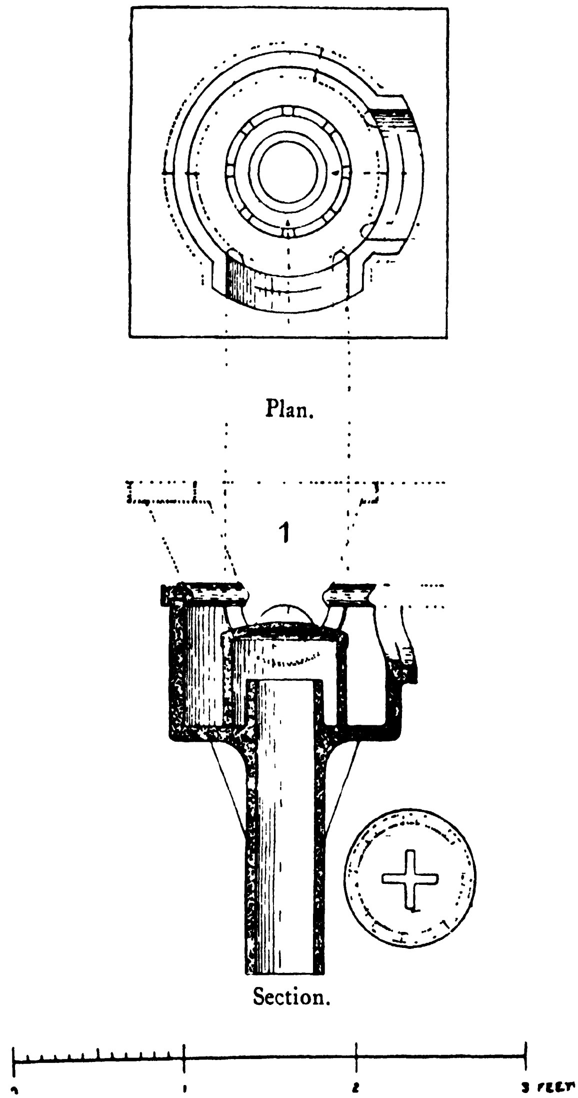


FIG. 91.—Plan and Section of Settling Pots Used in the Chemical Institute, Berlin.

Very elaborate forms of pots are used in some institutions. **Fig. 90** shows the arrangement at the bench ends at Leipzig and **Fig. 91** a plan and section of those at Fischer's chemical laboratories described in Chapter VI.

CHAPTER VI.

THIS final chapter is devoted to the description and illustration of a few recent designs of science buildings for the plans of which the author has to thank the architects and the authorities controlling such institutions. The number described is necessarily limited, but an attempt has been made to obtain some recent examples representative of schemes of different magnitude. School designs are first dealt with, after which a few university schemes are described, and finally an account of some foreign examples will be found.

SECTION I. RECENT SCHOOL DESIGNS.

Exmouth Street Elementary School, St. Pancras, London.

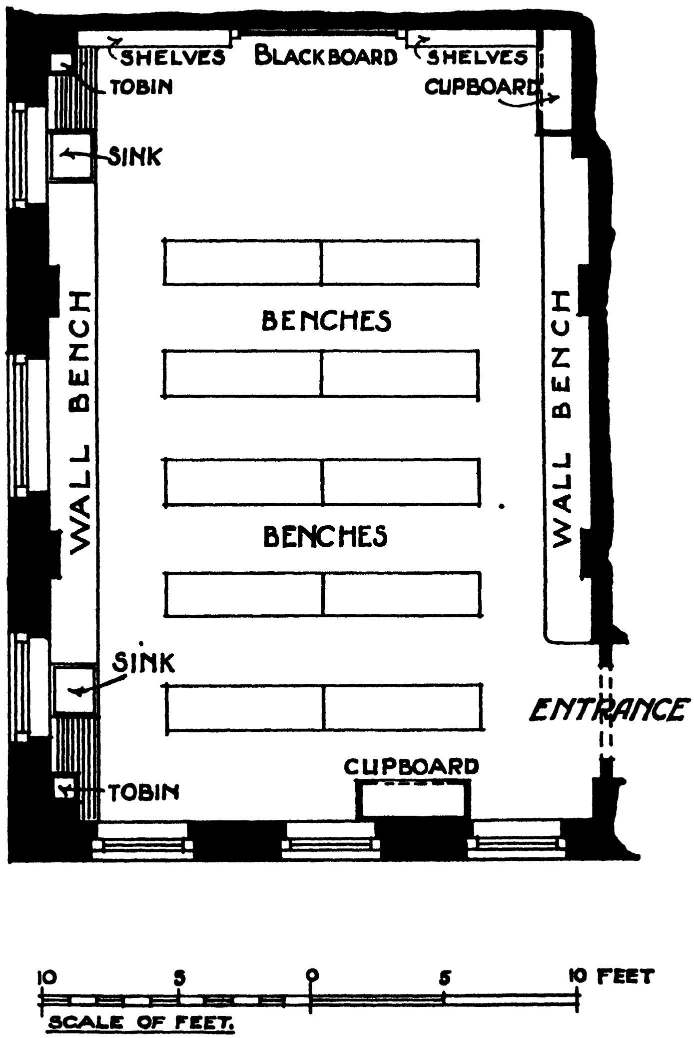
A new departure has been made in a recently opened elementary school, in the arrangement of two of the class-rooms in such a manner that they can be used for demonstrations or practical work in natural science. Both are identical in size and fittings, one being used by boys and the other by girls. A plan of one of these rooms, kindly contributed by Mr. W. E. Riley, F.R.I.B.A., when Architect to the London County Council, is shown in Fig. 92. About 30 ft. by 20 ft., and lighted on two sides, the rooms are fitted with strongly framed tables with teak tops, the three front rows being 2 ft. 6 ins. and the back rows 2 ft. 8 ins. high. These tables have flat tops and no drawers or lockers, and are 1 ft. 8 ins. wide. Under the long window wall is a side bench of the same width as the tables with teak top and two sinks, and has a fresh air inlet tube at each end. This bench, and that on the opposite wall, which is similar, are open below except for one cupboard about 2 ft. 6 ins. long. Open shelves on iron brackets and a blackboard are provided at one end of the room, and a glazed cupboard for storage of

apparatus, 18 ins. from front to back at the other. The room holds 40 seated at the tables, where the allowance is 2 ft. of desk each.

Forest School Physical Laboratory.

This forms an example of a very small detached physical laboratory and lecture room combined (Fig. 93), about 26 ft. by 21 ft. with a store or preparation room attached. The room holds 12 boys working at the tables and a similar number at desks placed in the centre. The floor is of wood blocks, the roof tiled and ceiled with a collar. By making the store ceiling somewhat lower, further storage is obtained in the roof, access to which is gained by a step ladder.

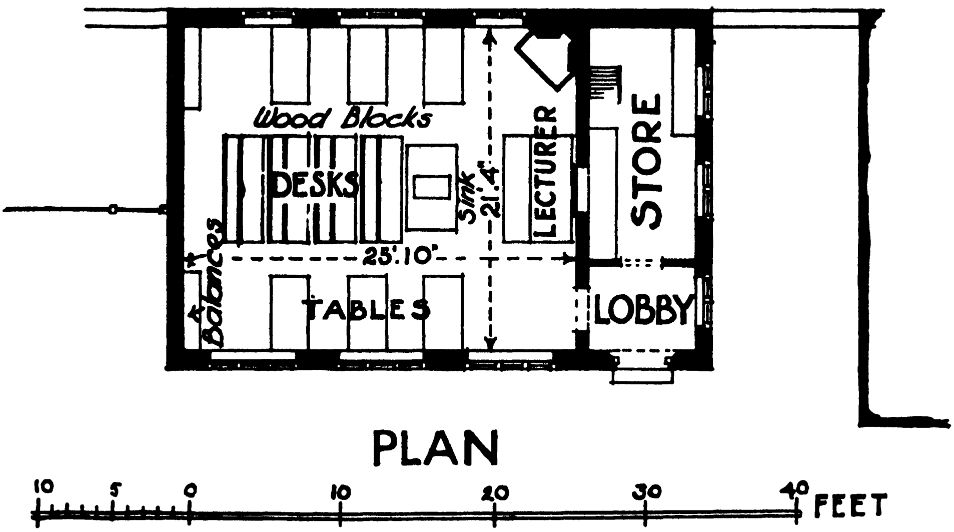
The fittings are in deal with pitch-pine tops to the tables. The working tables have one drawer at the side and another at the end. A large sink, bench, with cupboards below, occupies a central position. A good range of glazed cupboards is fixed above



[*W. E. Riley, F.R.I.B.A., Architect.*

FIG. 92.—Class-room Arranged for Use as Laboratory at Exmouth Street L.C.C. School.

the floor on the end wall. A feature of the lecturer's bench is the provision of open spaces for the deposit of class notebooks on the boys' side.



[*Alan E. Munby, F.R.I.B.A., Architect.*

FIG. 93.—Forest School Physical Laboratory.

The London Orphan School Laboratory, Watford.

This little building, shown in plan, **Fig. 94**, is given as an example of a very small general scheme where the greatest possible economy had to be effected in the matter of outlay. The laboratory was erected in 1907, and as the whole details of cost happen to be in the author's possession, including those for equipment, it may be interesting, for comparative purposes, to give the figures, which were: Building, including heating plant, £880; [1] Fittings, including desks and blinds, £277; [1] Apparatus (elementary chemistry, mechanics and heat), £187—Total £1344.

The building is of stock brick with 14 ins. external walls and slated roof. The walls are plastered internally, the floor of wood blocks on concrete. The building is 11 ft. high to the plate with the roof collar ceiled at 14 ft. The laboratory is 36 ft. by 22 ft. 6 ins., and possesses four double benches giving a length of 3 ft. 6 ins. each for 32 boys, with, however, only 25 sq. ft. of floor per head, a very conservative allowance, in extenuation of which, it may be added, that 14 is the maximum leaving age. The benches

[1] Made and supplied by Messrs. J. J. Griffin of Kingsway, W.C.

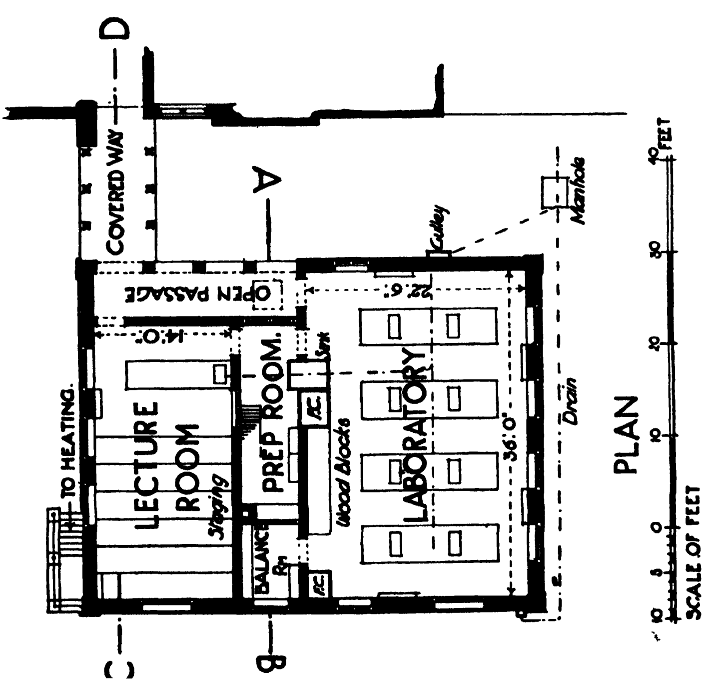


Fig. 94.

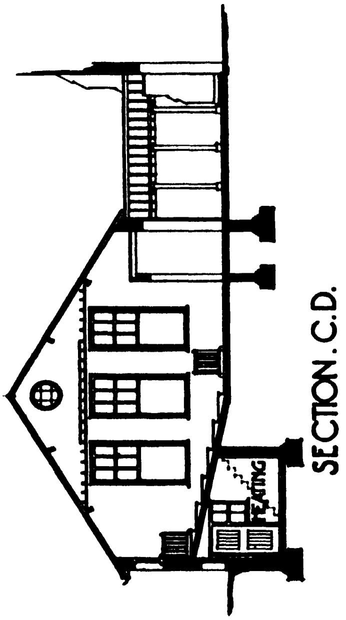


Fig. 96.

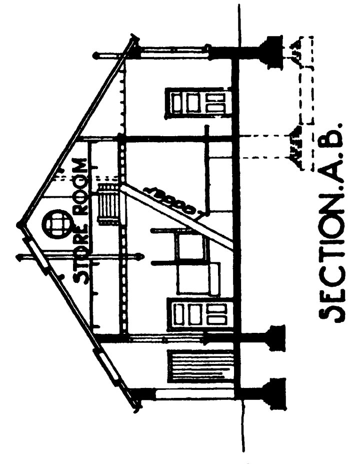


Fig. 95. [*Alan E. Munby, F.R.I.B.A., Architect.*

Science Block for the Boys' Side, London Orphan School, Watford.

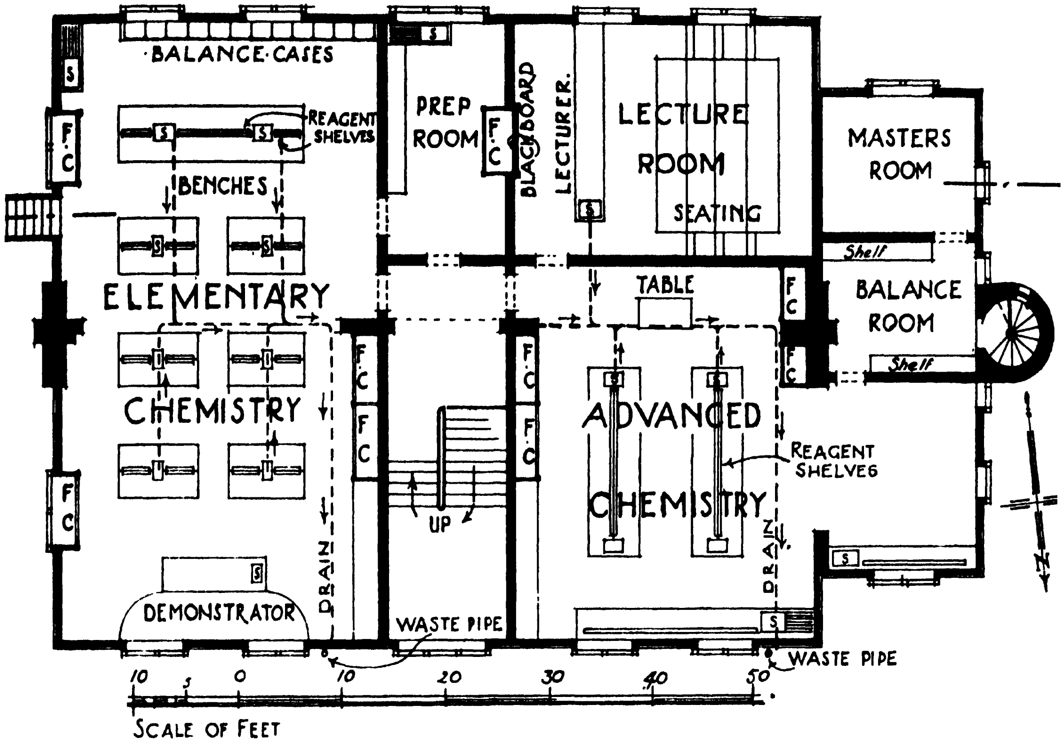
have teak tops, drawers and open shelves in place of cupboards below, and movable reagent shelves and sink covers to admit of the use of the benches both for chemistry and physics. Cases are fitted into the windows for balances, and gas for light and heat is supplied by an overhead system, the pipes not being fixed to the benches. One of the fume cupboards and a large sink serve both the laboratory and preparation room, from which room a step ladder gives access to a floor over and to the roof (as shown in the section, **Fig. 95**), the whole of which is made available for storage.

The lecture room, 14 ft. wide, has staging to the desks on a raised steel and concrete floor, under which is the boiler house, and the open passage floored over at 9 ft. gives some further storage space which is thrown into this room (section, **Fig. 96.**) The drains from the benches and lecture table are in 6 in. glazed channel pipes bedded in cement, and accessible by movable wooden covers in the flooring, and under the same covers are the gas and water mains.

Harrow School Chemical Laboratory.

A new chemical department was opened at Harrow School in 1916, the fittings and equipment for which were provided under the direction of Mr. Vassall, the senior science master, who was good enough to show the writer over the building, much of the detailed arrangement of which is due to Mr. Middleditch, one of the science staff. The plan, **Fig. 97**, is from drawings lent by the architect, Mr. Osborne Smith, F.R.I.B.A. The laboratory is on the top floor of an existing science block which previously possessed a high-pitched roof containing much wasted space. By a decrease in the unnecessarily high lower floor and the substitution of a mansard roof the whole floor area shown has been provided with practically no increase to the cube of the building. A section through the rooms is given in **Fig. 98**, from which it will be seen that the main stair and preparation room are covered by a flat, admitting of good top lighting to the main rooms, which have, in addition, side windows.

The elementary laboratory, about 52 ft. by 31 ft., containing six benches with tops 7 ft. 6 ins. by 4 ft. 6 ins. and one 18 ft. by 4 ft. 6 ins., accommodates 30 boys at about 52 sq. ft. per head. In addition to the benches the room contains a demonstration table, fume cupboards, a combustion bench, balance cases, a large sink, and reagent shelves. Mr. Vassall has been



[*Osborne Smith, F.R.I.B.A., Archi*

FIG. 97.—Chemical Laboratory, Harrow School.

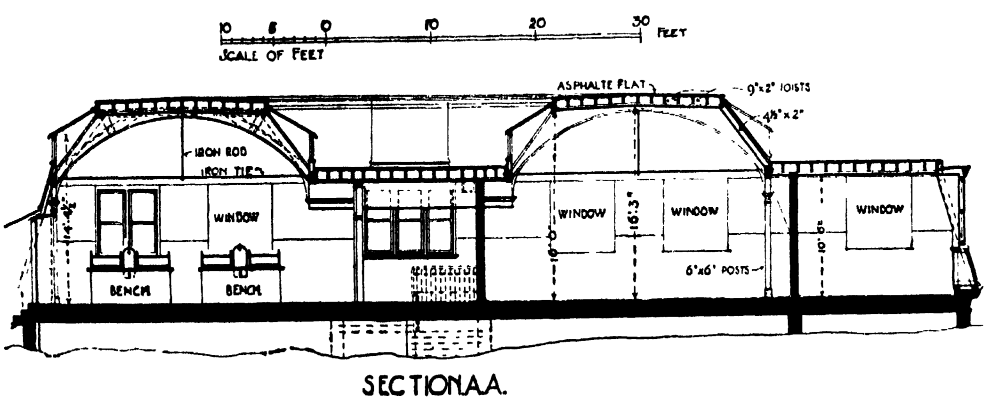


FIG. 98.

[*To face page*

at much pains to ensure the maximum of wall space with due regard to efficient lighting. Thus the blackboards are not on the walls, but arranged on pulleys in front of certain windows, being pushed down into the panelling between the sill and floor when not in use. The advanced laboratory contains two 16 ft. island and one 18 ft. wall bench, giving places for, if necessary, 20 boys, apart from the large alcove which is chiefly devoted to literary work and research by the staff. A lecture room with raised seating, a balance room, master's room, and store rooms complete the accommodation.

The drainage, which presented the usual difficulties to be contended with when a "fire-proof" wood-block floor is used, has been already described on page 145. Where floor drainage runs under the benches the lockers are omitted.

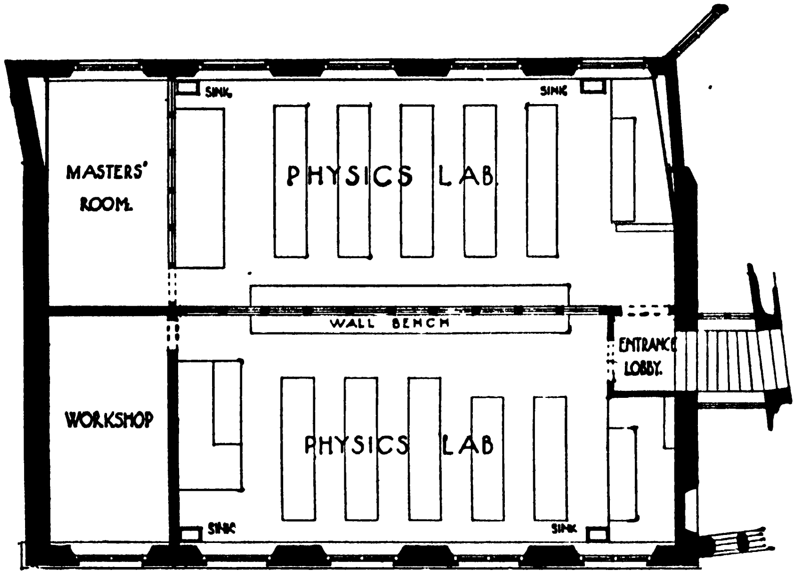
The benches have glass reagent shelves, and drawers and lockers. A system exists of making every boy display the whole of his small set of apparatus on the bench top for inspection before the close of the class, and is said to work well and prevent much loss and misplacement, while only occupying some three minutes.

The fume cupboard bases consist of two white glazed fireclay slabs about 3 ft. by 2 ft. 3 ins. and $2\frac{1}{2}$ ins. thick, and in some cases these are perforated for a small sink. These cupboards stand in the windows.

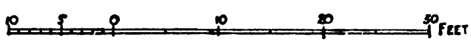
The balance cases shown at the end of the elementary laboratory are built into the windows and designed for use standing, the bench top being 3 ft. 7 ins. above the floor, and the space below is devoted to cupboards with sliding doors. The ventilation of the fume cupboards is effected by a fan. All doors in the laboratory are arranged to swing.

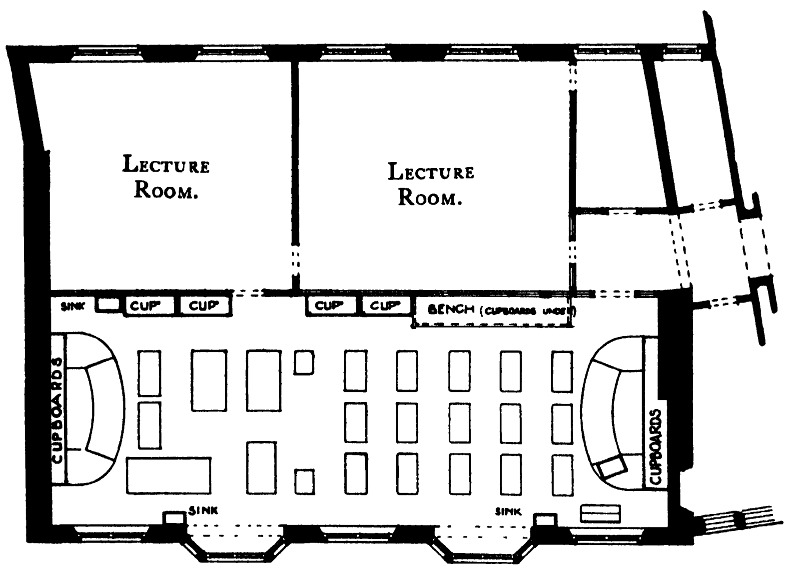
Manchester Grammar School, Physical Laboratory.

This block, built on the somewhat restricted site of a previous physical laboratory, consists of three floors, below which is a basement devoted to a swimming bath and cloak rooms. The ground floor comprises two junior laboratories, each about 47 ft. by 23 ft. with a demonstration platform at each end. The classes consist of about 30 boys, giving an area of some 36 sq. ft. per head. Long narrow tables, at which the boys sit on one side only, are used in these rooms. These laboratories each possess two sinks in addition to those on the lecture tables, and also a good range of glazed



GROUND PLAN.





1ST FLOOR PLAN

[*T. P. Figgis and Alan E. Munby, F.F.R.I.B.A., Joint Architects.*

FIGS. 99 and 100.—Physical Laboratories, Manchester Grammar School.

cupboards. Adjoining are a master's room and a workshop containing a powerful electric motor, operating shafting for several machines for repairing and constructive work. On the first floor the advanced laboratory, 59 ft. by 23 ft., is fitted with solidly made single tables 4 ft. by 2 ft., and again has a lecture table at each end. Adjoining this room are two lecture rooms with tables for experimental demonstrations on platforms, but no raised staging, ordinary desks being preferred. Ten ampere supplies are arranged for several points in the advanced laboratory. Good cross light is obtained without loss of useful wall space, by glazed screens to the upper part of the central partition wall on both floors. Plans of these rooms are shown in **Figs. 99** and **100**, and the author is indebted to Mr. J. L. Paton, the High Master and the senior physics master for assistance in their production.

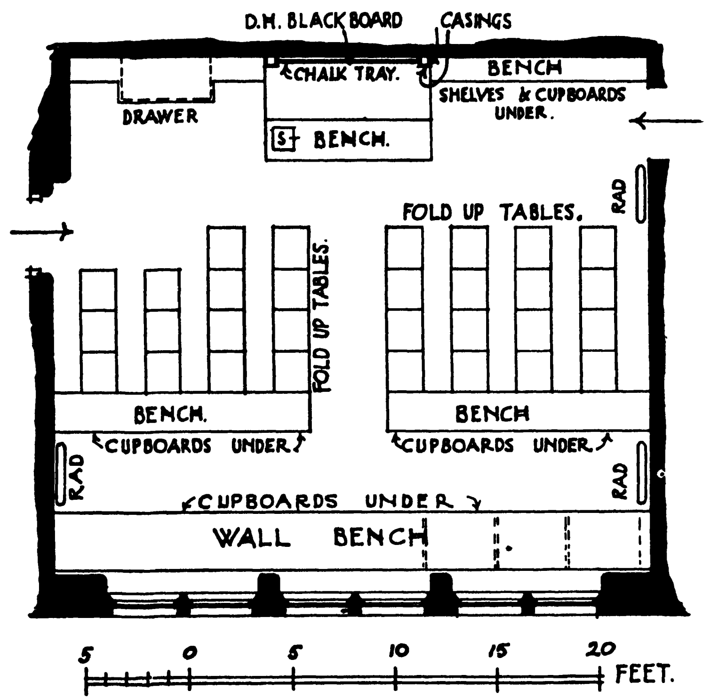


FIG. 101.—Biological Lecture Room and Laboratory, Charterhouse School, as arranged by the Senior Science Master, Mr. O. H. Latter.

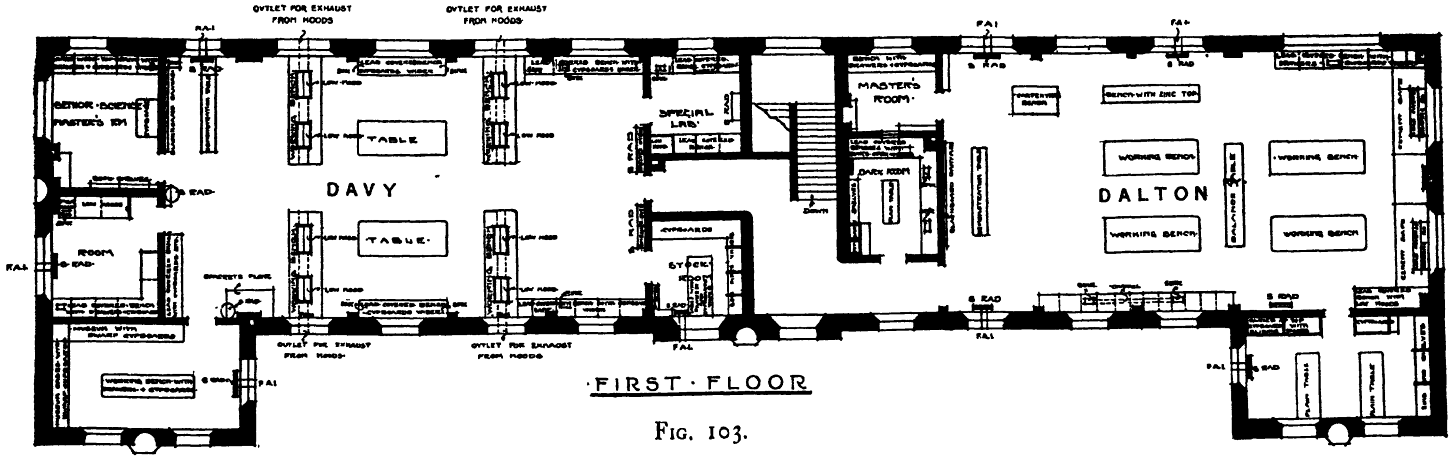
Biological Laboratory, Charterhouse School.

Fig. 101 shows the main room of the biological department at Charterhouse School arranged by Mr. O. H. Latter, the senior science master, under whose guidance the writer had an opportunity of going over the building. This plan forms an example of a combined lecture room and laboratory for biological and botanical work which is the outcome of considerable experience.

Under the window facing north, a bench with teak top 2 ft. 10 ins. wide and 2 ft. 11 ins. high provides working space at 3 ft. 6 ins. per head for the use of the microscope. Under each place is a 5 in. drawer and cupboard 1 ft. 11 ins. high with toe space below, while 1 ft. 5 ins. is left for knee space, the whole being 2 ft. 1 in. wide. On the other side of the gangway another similar bench is placed but without cupboards. Separate seats and desks 2 ft. long for each student are placed in two groups at right angles to the window wall, and here a good deal of practical work is also done. On the back wall are a double hung blackboard, glazed cupboards, with drawers below large enough for diagrams, a set of open shelves and a small lecture table on a platform, next to which are electric controls for lantern and bench lights. The room seats 24, but for senior practical work is suitable for 16. The department further includes a room facing east where a live tank is installed, used for special work, a small greenhouse, a workshop and mounting room and space for storage.

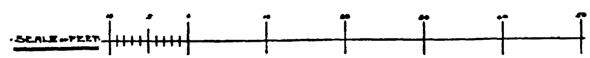
Science Rooms at Christ's Hospital, Horsham.

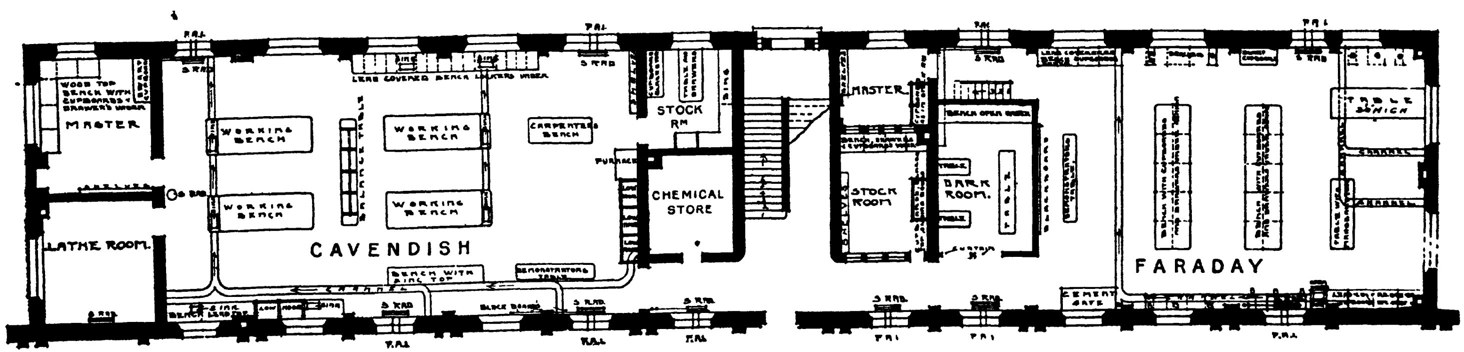
The description of this building and the illustrations by Mr. C. E. Browne, the senior science master, are taken from a paper by Prof. H. E. Armstrong, and are made available through his courtesy and that of the Editor of the R.I.B.A. Journal, and the architect, Sir Aston Webb. The floor area of this science block covers some 10,000 sq. ft. and comprises four main rooms (**Figs. 102-3**) of about 2000 sq. ft. each on two floors in addition to small rooms for the staff, dark rooms, and store rooms. The scheme is arranged to admit of the maximum of practical work with the minimum of formal teaching; even the name "laboratory" is banned in favour of "workshop," and no separation of the rooms into chemical and physical departments is made. No lecture room is provided, but a demonstration bench is placed in each laboratory with space for seats before it in two of these rooms, while in the other two the boys stand, but have a narrow desk before them on which they can take notes. The balances are used in the laboratories upon a double island bench 12 ft. by 2 ft. and 3 ft. 6 ins. high carrying a glazed enclosure which opens at sides and ends. Each laboratory has a store room where unfinished experiments are also taken care of. For work involving water, lead-covered benches are used, others have teak tops. Prof. Armstrong considers that the usual provision for water in school



·FIRST·FLOOR

FIG. 103.





GROUND FLOOR

FIG. 102.

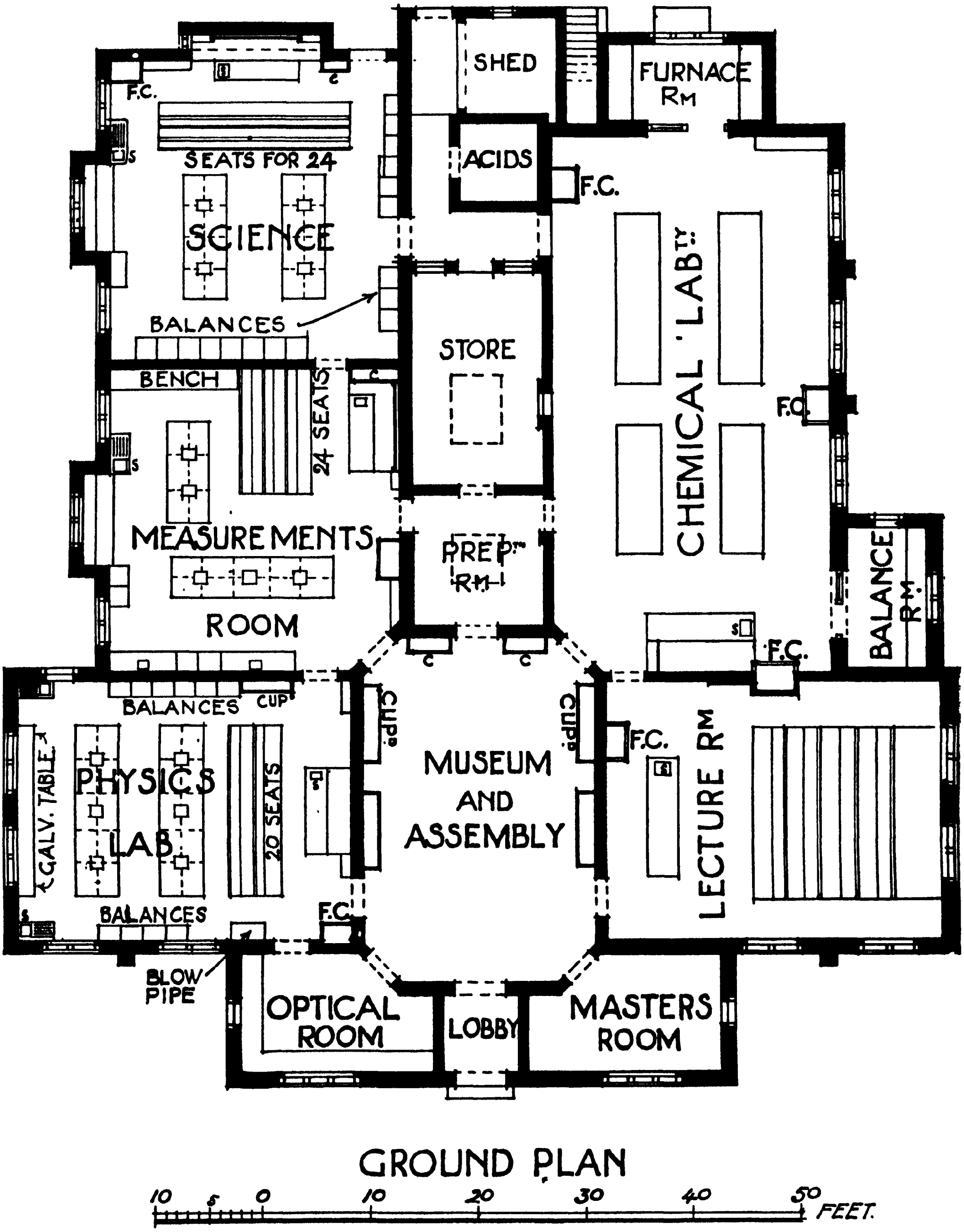
[*Sir Aston Webb, P.R.A., F.R.I.B.A., Architect.*

Science Block, Christ's Hospital, Horsham, as arranged by Prof. H. E. Armstrong.

laboratories is unnecessarily lavish. In the first floor rooms all sinks, which are made of wood, pitched inside, are placed on the walls. Bottle shelves on the benches are omitted. In their place lengths of gas pipe 3 ft. apart are fixed vertically on the benches and attached at their tops to two parallel horizontal pipes running the length of the bench and joined at their ends to form a complete circuit, to which is attached the gas service from the ceiling above. The uprights are used as clamp rods, and by placing short boards on the horizontal pipes a high shelf may be improvised. Each working place has four cupboards arranged in two tiers possessing a drawer inside them. The wood sinks have been referred to on page 28. The lead wastes to these sinks are flanged at the top, secured between two blocks, one outside and one inside, bolted together and well treated with pitch. In addition to the four laboratories the department contains two dark rooms, one for optical work on the ground floor, the other for photography above it, and a small repair shop, though repairs are also effected at carpenters' benches in two of the laboratories themselves.

Science Building, Shrewsbury School.

This interesting, recently completed building is shown in **Fig. 104**, prepared from drawings kindly lent by the architect, Mr. Lloyd Oswell, A.R.I.B.A. For the description the author has to thank the senior science master, Mr. C. J. Baker, who has devoted considerable care to the scheme both as regards design and equipment. A one storey building for the teaching of chemistry, physics, and natural history, Mr. Baker's main idea in the design was to centralize the attendant's and store rooms and to avoid waste of space in corridors, and it will be noticed that the entrance hall, also used as a museum, gives access to three of the four laboratories and the lecture room besides the two smaller rooms on the frontage. The remaining laboratory has an external door or can be approached through the measurements room. The attendant can obtain independent access to all the rooms and can be summoned by speaking-tubes which have a different whistle pitch for each laboratory. The doors are made of extra thickness, which is found to reduce the transmission of sound. To deal shortly with the individual rooms—the master's room is fitted up as a small laboratory for private use. The lecture room, 31 ft. by 24 ft., has seating for about 60. The table is well supplied with services and is lighted by a



[*A. E. Lloyd Oswell, A.R.I.B.A., Architect.*

FIG. 104.—Science Block, Shrewsbury School, as arranged by the Senior Science Master, Mr. C. J. Baker.

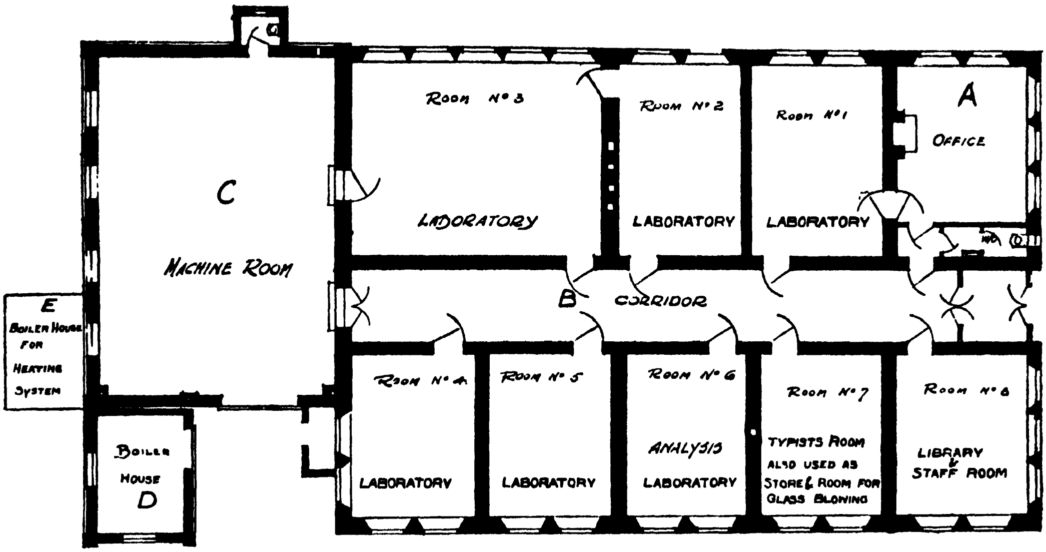
series of ceiling lights placed in front of an opal glass surface, and special lights screened from the students are used for the blackboard, behind which is a lantern screen on the wall surface. The chemical laboratory, 50 ft. by 25 ft., contains 28 places; the sinks (not shown) in these benches can be used for experiments with gases. Water pumps are provided on the benches and also small pilot gas jets to economize the gas used by the bench burners, which can thus be relighted at will. By the use of space under wall benches (not shown on the plan), which provides 30 extra lockers, 86 lockers in all are obtained. On these side benches are twelve balances specially designed for this laboratory with opal glass backs, glass pans, and weights in the balance board. Distilled water is made in the attendant's room and supplied through a pipe in the wall. The bench tops are of teak, waxed, the floor of maple blocks, and the drains of glazed channel pipes. The furnace room at the end of the laboratory is used for blowpipe and other noisy or noxious work and is separated from the laboratory by a glazed screen. The attendant's and store room are well fitted with benches, sinks, and supplies, and a separate room is provided for acids. At the further end of the building, the laboratory called "Science" on the plan, is a combined laboratory and lecture room and is used for chemical work. The recess at the end of this room accommodates a fully equipped lecture table. The measurements room, in which natural history (elementary botany and physiography) is also taught, is again a combined room for theoretical and practical work. The benches have gas and water, and the room contains twelve balances. The adjoining physical laboratory, fitted like the preceding rooms, provides for a class of 22, and off it is an optical room. Dark blinds are installed in all the rooms except the large chemical laboratory.

SECTION II. RECENT DESIGNS FOR ADVANCED WORK.

Chemical Laboratory, Chiswick.

A plan of this small building (**Fig. 105**) is shown, thanks to the courtesy of the Ministry of Munitions and the Official Receiver. Its interest lies chiefly in the fact that it was erected by Germans in 1914. Its exact purpose is not known, but it was evidently designed for research and investigations on a commercial scale. It has been used during the war in connection with oil products. The building consists of five small and one larger laboratory,

a library, two offices, and a large machine room, attached to which is a small boiler house. The fittings are of no special interest.



GROUND PLAN:

FIG. 105.—Research Laboratory, Chiswick, London.

The Sir John Cass Institute, Aldgate, London.

The chemical laboratory of this Institution possesses some interesting features. Originally a gymnasium, it was recently converted into a laboratory under the personal directions of the Principal, Dr. Keane, who was kind enough to take the author over it and allow him to prepare the plan, **Fig. 106,** which shows a very successful instance of the conversion of an existing building to the uses of science. Situated on a top floor, and top lighted with subsidiary side windows, the laboratory, 74 ft. by 36 ft., is fitted with twelve working benches 8 ft. by 5 ft. for four students each, giving 48 places. Each place possesses two drawers and cupboards, so that locker accommodation exists for 96 students. The gangway spacing is ample, but is not found extravagant when the benches are fully occupied. In converting this room the difficulty of drainage—the existing floor being of solid fire-resisting construction—was met by Dr. Keane by forming a new joisted and boarded floor on the top of the old one over the whole area with two steps up to it in the approach corridor.

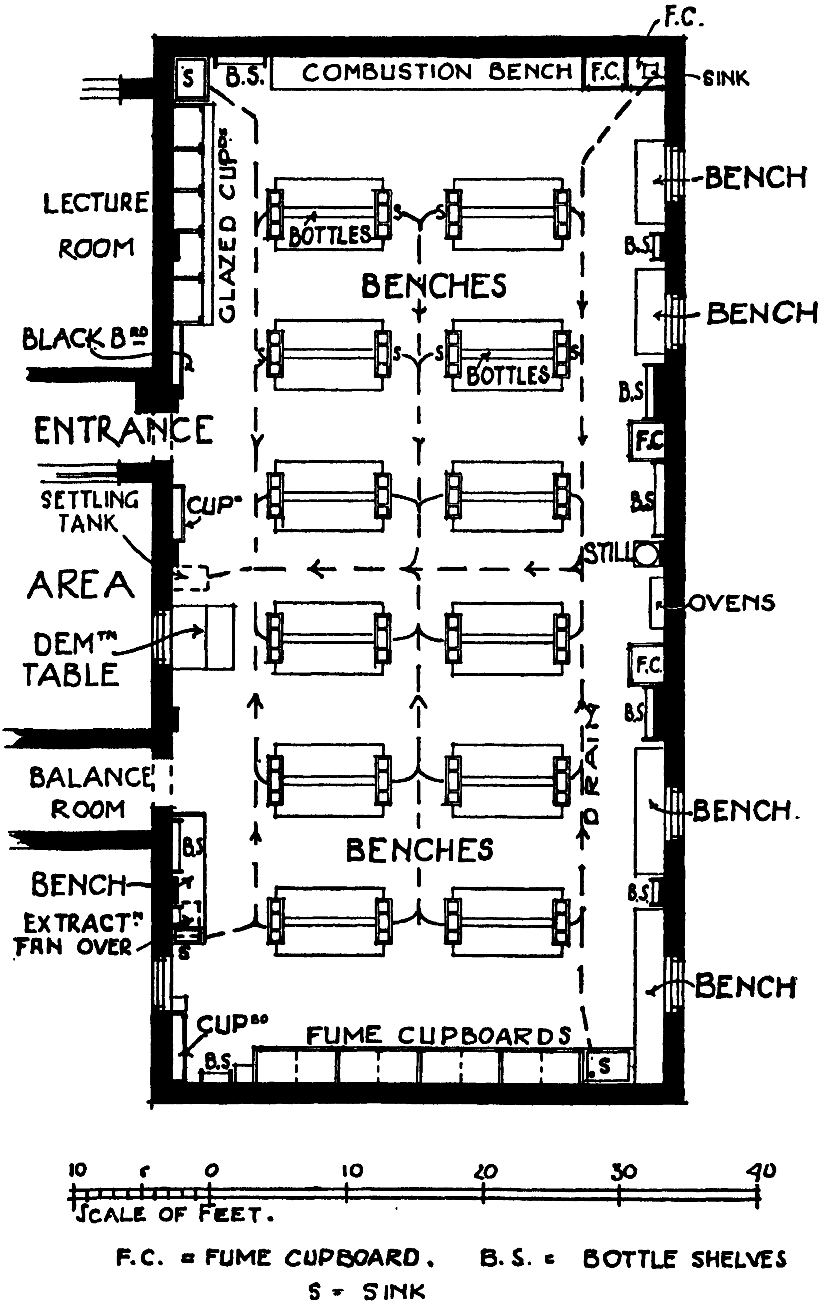


FIG. 106.—Chemical Laboratory at the Cass Institute, London, as arranged by the Principal, C. A. Keane.

This floor is $11\frac{1}{2}$ ins. deep and in it the whole of the drainage is arranged. This drainage presents a most successful example of the use of pitched wood troughs, which are made of 1 inch deal. These are rectangular in section and open at the top, their internal dimensions range from about 3 ins. wide and $2\frac{1}{2}$ ins. deep in the branches to $4\frac{1}{2}$ ins. wide and 3 ins. deep in the main trunks. The lines of drainage are shown on the plan, and it will be noticed that the location of the sinks at the ends of the working benches has made it possible to keep the whole of these drains in the gangways where the floor boards are cut and connected by rough battens underneath. These covers merely take a bearing on the floor joists, a very simple and inexpensive form of access is thus provided to the whole system. The troughs are made in lengths up to about 12 ft. The branches are connected at right angles (the curved lines on the plan merely indicating direction of flow). The fall is arranged from both ends of the room to a central trough which discharges into a similarly constructed settling tank about 21 ins. square and 9 ins. deep, which has an overflow in lead $3\frac{1}{2}$ ins. above the bottom of the tank discharging into the general drainage system.

The benches have teak tops and are without bottle racks, but space is provided for one row of bottles for each worker on opal glass. The sinks, designed by Dr. Keane, are of white glazed ware with movable fireclay grids. Cast in one piece with them at each end is a compartment about 8 ins. square and the same depth, containing a movable galvanized wire tray for solid rubbish. These compartments have no outlets to the sink.

The sink and waste boxes measure externally 3 ft. 3 ins. by 10 ins. by 9 ins. deep, and the untrapped lead wastes discharge directly into the drains without the intervention of settling-pots.

Other fittings are shown upon the plan, and comprise a long combustion bench at one end with stone top and hood over, fume and distillation cupboards, a small demonstration table on a platform, side benches, two large sinks, shelves, and glazed cupboards for apparatus.

Incandescent gas standards have been installed for light on the benches to avoid the introduction of another service of pipes, though electricity is employed for ceiling lights.

Ventilation is arranged from the fume and distillation cupboards by a graded iron trunk suspended from the ceiling attached to a fan and motor (about 1 h.p.). This trunk has an initial diameter of about 4 ins. increasing

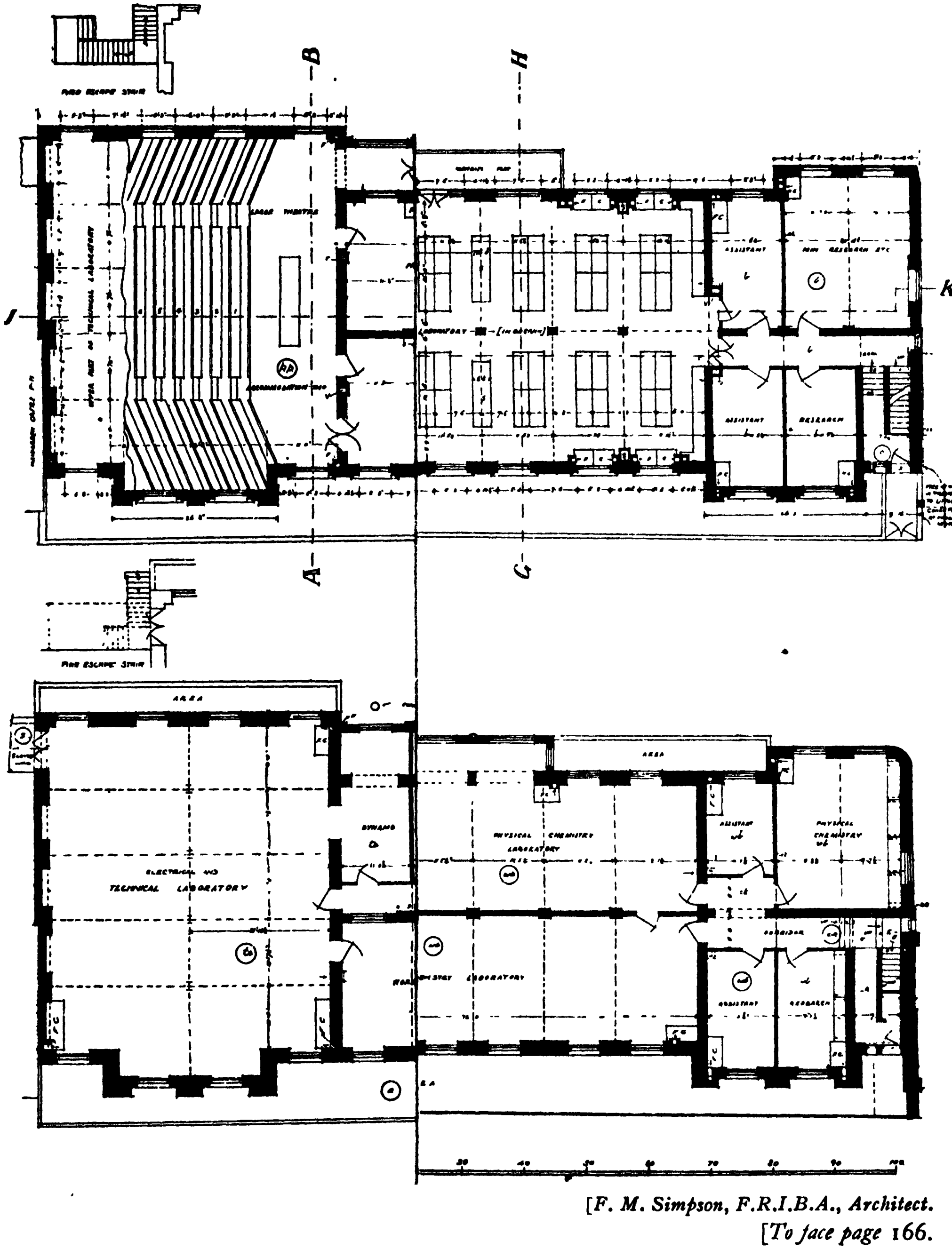
to 15 ins. at the fan and possesses 17 openings; it is said to work satisfactorily with the occasional use of one damper.

University College, London, Chemical Department.

This building, opened in 1916, forms an extensive block over 300 ft. long and about 50 ft. deep, erected from the designs of Prof. F. M. Simpson, F.R.I.B.A., who has kindly contributed the plans, **Figs. 107-10,** and the writer is much indebted to the architect and to the professorial staff, particularly to Prof. Donnan, for facilities for obtaining details of the arrangements which form the outcome of the study of the best-known modern examples of chemical laboratories.

Basement.—The basement floor, apart from a small area sunk to a lower level for the low-pressure hot-water plant and steam plant, is devoted to technical and physical chemistry. The technical laboratory, about 52 ft. by 45 ft., is below the main lecture theatre and is devoted to special researches on a commercial scale. It adjoins the workshop, well equipped with light machinery, next which is a switchboard room and research laboratory, and under the main entrance a constant temperature room with double walls. On the other side of the corridor is a liquid air room, already described and illustrated on page 71. The rest of this floor is given up to two large laboratories and smaller rooms for physical chemistry, including a dark room for optical and photographic work, balance, instrument, assistant's and research rooms. The physical chemistry laboratories contain cross benches with teak tops of the type usual for advanced general work, those in the front room adjoin the windows and are 12 ft. 10 ins. long, 6 ft. wide and 35 ins. high, with drawers and cupboards, two drip sinks near the wall, and one at the free end, and have gangways 6 ft. 3 ins. wide between them. Two students work at a bench, one on each side. The special benches for large apparatus are placed along the centre wall between the two laboratories, and are described and figured on page 63. Well set back from the road and aided by prismatic glass, this floor is excellently lighted.

Ground Floor.—The main lecture theatre, 52 ft. by 45 ft., which runs through two floors, accommodates 240 students on raised seating. The lecture table, 23 ft. 8 ins. long, has a teak top with a flush tiled area about 40 ins. by 30 ins. at each end for combustions, and is filled in below at each end only with three drawers and one cupboard about 6 ft. long. Ten water, and the same number of gas cocks (all on the lecturer's side) are pro-



[*F. M. Simpson, F.R.I.B.A., Architect.*

[*To face page* 166.

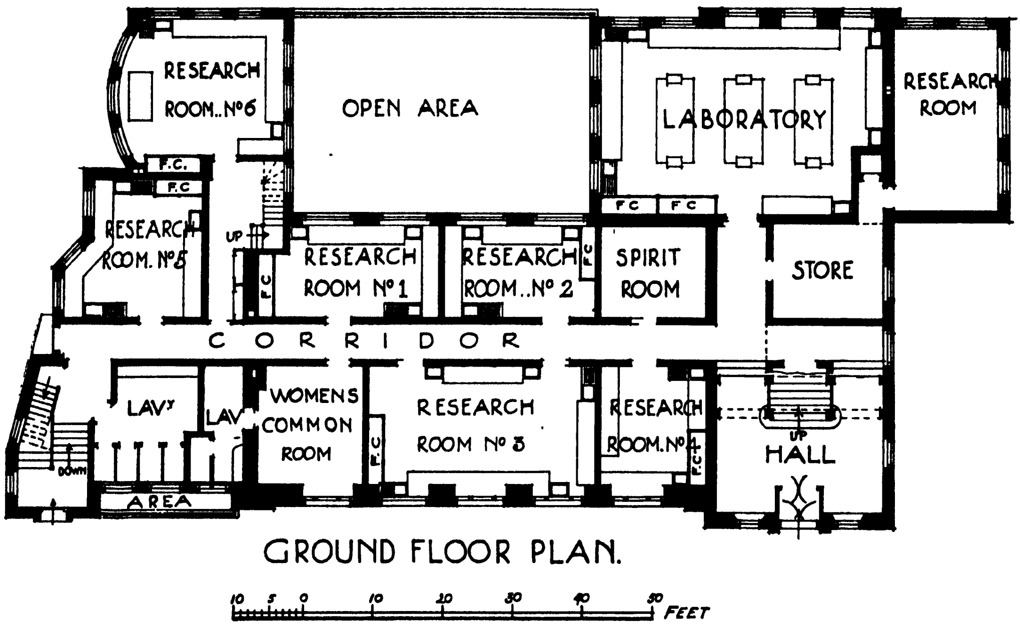
vided, and leads for electric power are arranged on the other side (see page 43). Sinks are not placed in the table but one is provided adjoining each end. There are four 4 in. draught holes in the table, and double hung blackboards and lantern and diagram screens on the wall behind.

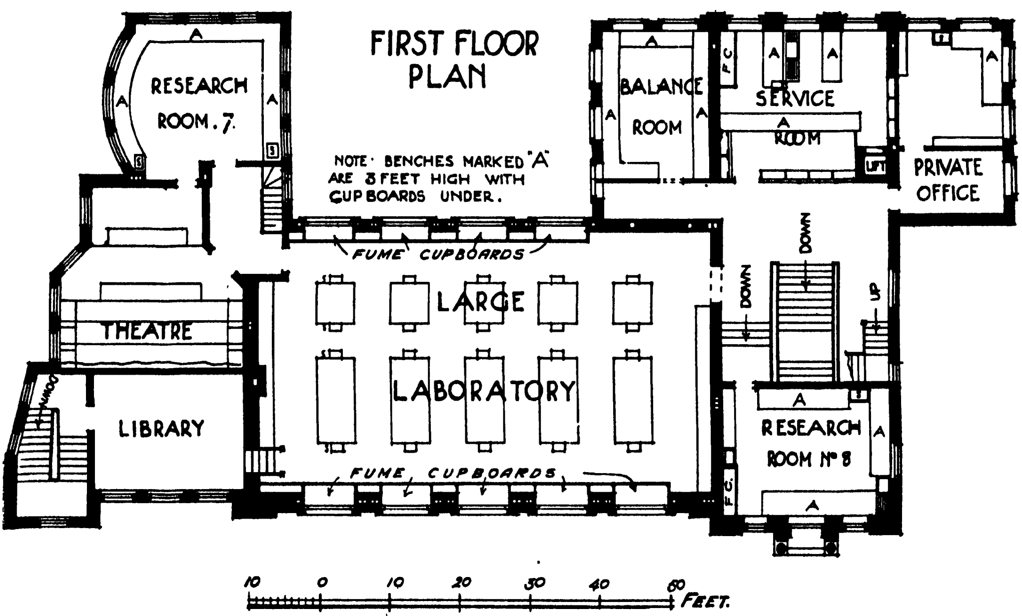
The preparation room adjoining, about 34 ft. by 21 ft., has a large centre table well stocked with drawers, a range of glazed wall cupboards, a combustion bench, fume cupboard and two sinks, one being 3 ft. 6 ins. by 1 ft. 8 ins. by 12 ins. deep. The smaller lecture room is similarly but rather more simply furnished and seats 110 students.

The furnace room[1] possesses side and central benches in iron framing with concrete and tile tops, the side bench having a hood as described on page 59. There are four sinks, and the gas supply is arranged for heavy work. Off this room is a balcony with a glazed roof for special experiments. A large balance room with separate slate benches on brackets and brick piers adjoins the advanced inorganic laboratory, which is a room 72 ft. by 43 ft. containing twelve 12 ft. double benches for 4 students each. These benches, 5 ft. wide, with gangways 5 ft. 3 ins. between them, have concrete tops covered with red tiles. Each bench has two drip sinks near the centre and a sink with draining board attached to each end, 17 ins. by 11 ins. by 9½ ins. deep inside. The reagent shelves are of pitch pine. In the windows are large fume cupboards, floored with white glazed tiles, and in the centre of the room a special range of shelves for large aspirators with a glazed open channel beneath the taps, connected to drainage (already figured on page 61). At the end of the room are wall benches and ovens. The research rooms beyond are fitted with tiled combustion benches and fume cupboards, and on one or more of the walls, with narrow teak shelves supplied with gas, water, and drainage, to which movable tables can be brought, thus leaving the centre of the room free for arrangement in any manner desired.

First Floor.—The first floor is devoted to organic chemistry and is planned similarly to the floor below. The main laboratory benches have a low-pressure steam supply and the tops are of teak, preferred by the professor of organic chemistry, to tiles. In the windows again are eight fume cupboards 6 ft. by 3 ft. with sashes giving an opening 4 ft. high. The ovens are heated by steam at 30 lb. pressure. Aspirator shelves, as above described, and a glazed cupboard for special chemicals are provided in the centre of the

[1] Operation room on plan, next stair.





[*Paul Waterhouse, F.R.I.B.A., Architect.*

FIGS. 111 and 112.—Organic Chemical Laboratory, Oxford University.

room. The combustion rooms are fitted in a manner resembling generally the furnace room below. The store near the lecture room has a counter across the room near the door, and a window bench filled with drawers below, and in the centre a large open tier of shelves 20 ft. long and 5 ft. wide, 17 ins. apart, reaching from floor to ceiling. On the inner wall are glazed cupboards.

Second Floor.—The elementary laboratories both for inorganic and organic work occupy one part of this floor, and are fitted similarly to those already described. The other portion is devoted partly to general research and partly to medical chemistry, but at the time of inspection this was utilized for researches in connection with the war.

Organic Chemical Laboratory, Oxford University.

This building, opened about 1914under the direction of Dr. W. H. Perkin, forms an interesting example of university development. The writer had an opportunity of inspecting it under the guidance of Dr. N. V. Sidgwick, and is indebted to the architect, Mr. Paul Waterhouse, F.R.I.B.A., for a loan of his plans, **Figs. 111-13.** The ground floor, slightly sunk below ground level, is devoted to research rooms, where the fittings are mostly arranged round the walls in order to give as much central free space as possible for special apparatus.

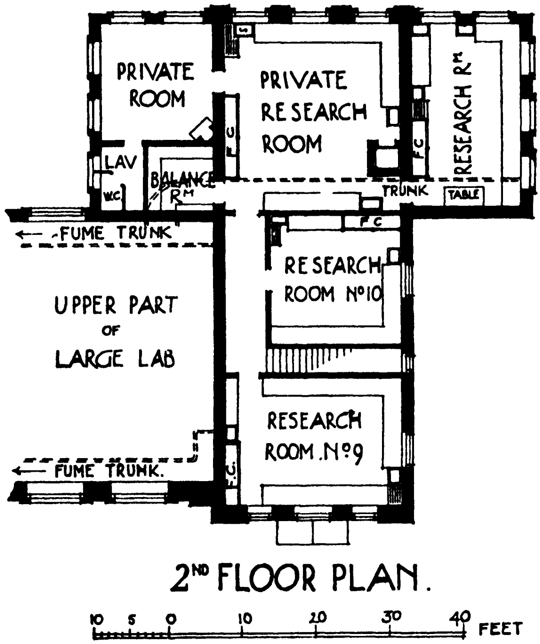


FIG. 113.—Organic Chemical Laboratory, Oxford University.

The first floor contains the large general laboratory, 64 ft. by 35 ft. equipped with five benches 11 ft. 2 ins. by 5 ft. 6 ins., and five smaller ones 5 ft. 4 ins. long, giving in all 30 places with about $5\frac{1}{2}$ ft. bench length each. The room is 20 ft. high and excellently lighted by high side windows and a central lantern. Fume cupboards with sashes opening to a height of 4 ft.

are placed in the windows, their roofs stopping against the transoms. Adjoining this laboratory, but also separately entered at the other end of the building, is a small lecture theatre in which both seating and lecture table are raised, and under the upper part of the staging, very happily designed, is a small library. In addition to research and balance rooms, a well-arranged service room (dispensary), with counter and stock solutions over a drainage channel, is provided in a central position near the main staircase.

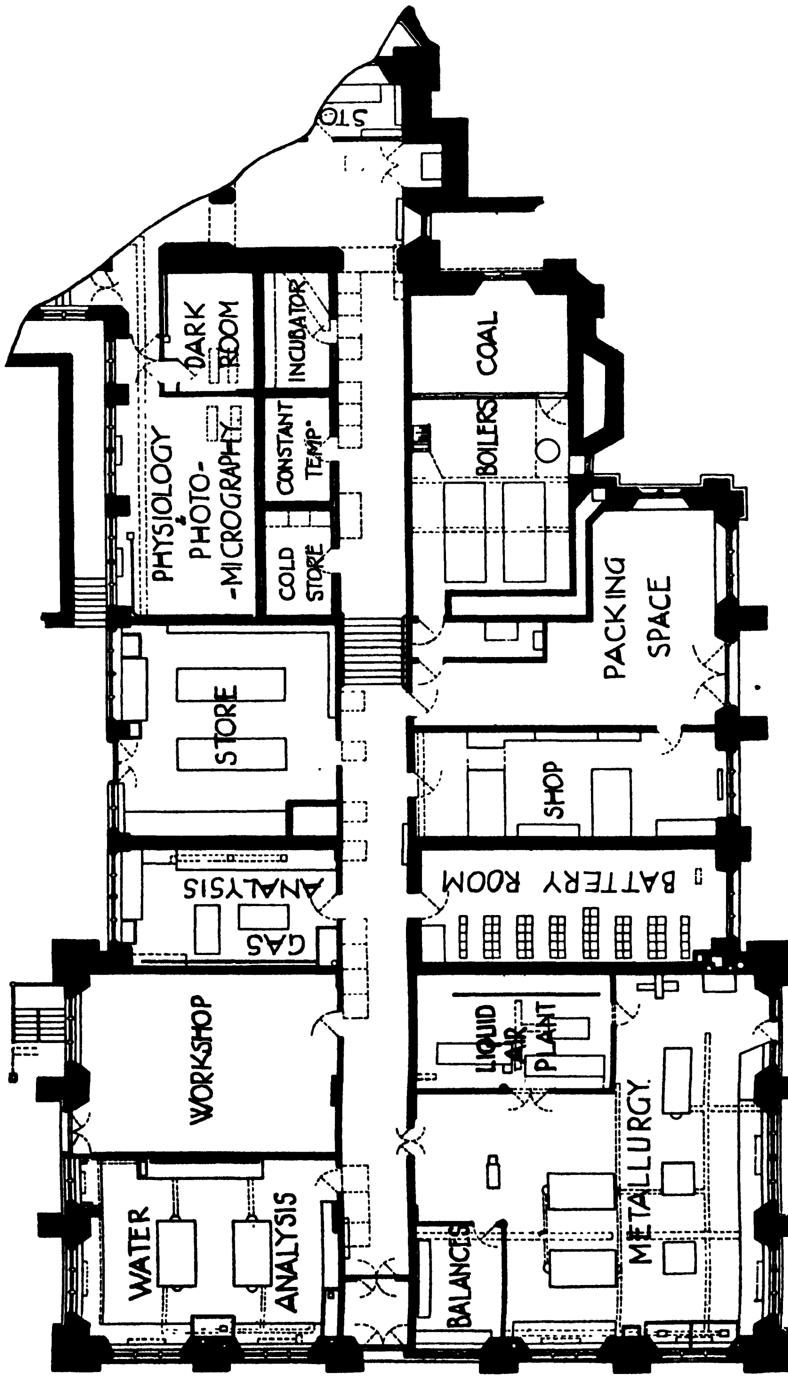
The second floor is in the hands of British Dyes Ltd., under the direction of Dr. Hope, and contains also Dr. Perkin's private room and laboratory. The fittings resemble those usual for higher chemical work, the benches are again placed round the walls and any central fittings are movable.

With regard to details of bench construction the working bench tops are of teak, and shallow lead channels are provided under water cocks for drainage. Filter pumps are attached to jets over the sinks. The benches in the general laboratory have two glass shelves for bottles, one 15 ins., the other 25 ins. above the bench tops, and these shelves are 6 ins. and 8 ins. wide on each side respectively. Individual electric lights are fixed to the wood standards of these shelves, and these lights are provided with opal covers as a protection to the eyes and with brass sleeve pieces over the holders to save the latter from corrosion. A sketch of one of the general laboratory benches is given in Chapter II. The laboratories are ventilated on the central fan system.

Chemical Department, Bristol University.

This department was opened in 1910, and the author has to thank Prof. F. Francis for allowing him to inspect it under his guidance, and Messrs. Oatley and Lawrence, F.F.R.I.B.A., the Architects, for contributing the plans shown in **Figs. 114-16.** The basement contains a large metallurgical laboratory, adjoining which is the general power plant, including that for liquid air next to the battery room, a workshop large enough to enable students to make their own repairs, an unpacking room, and the boiler house complete the rooms on one side of the corridor, while on the other are laboratories for biochemistry and research,[1] stores, and small rooms for special purposes. Dangerous chemicals are stored in a small detached concrete erection outside the unpacking room.

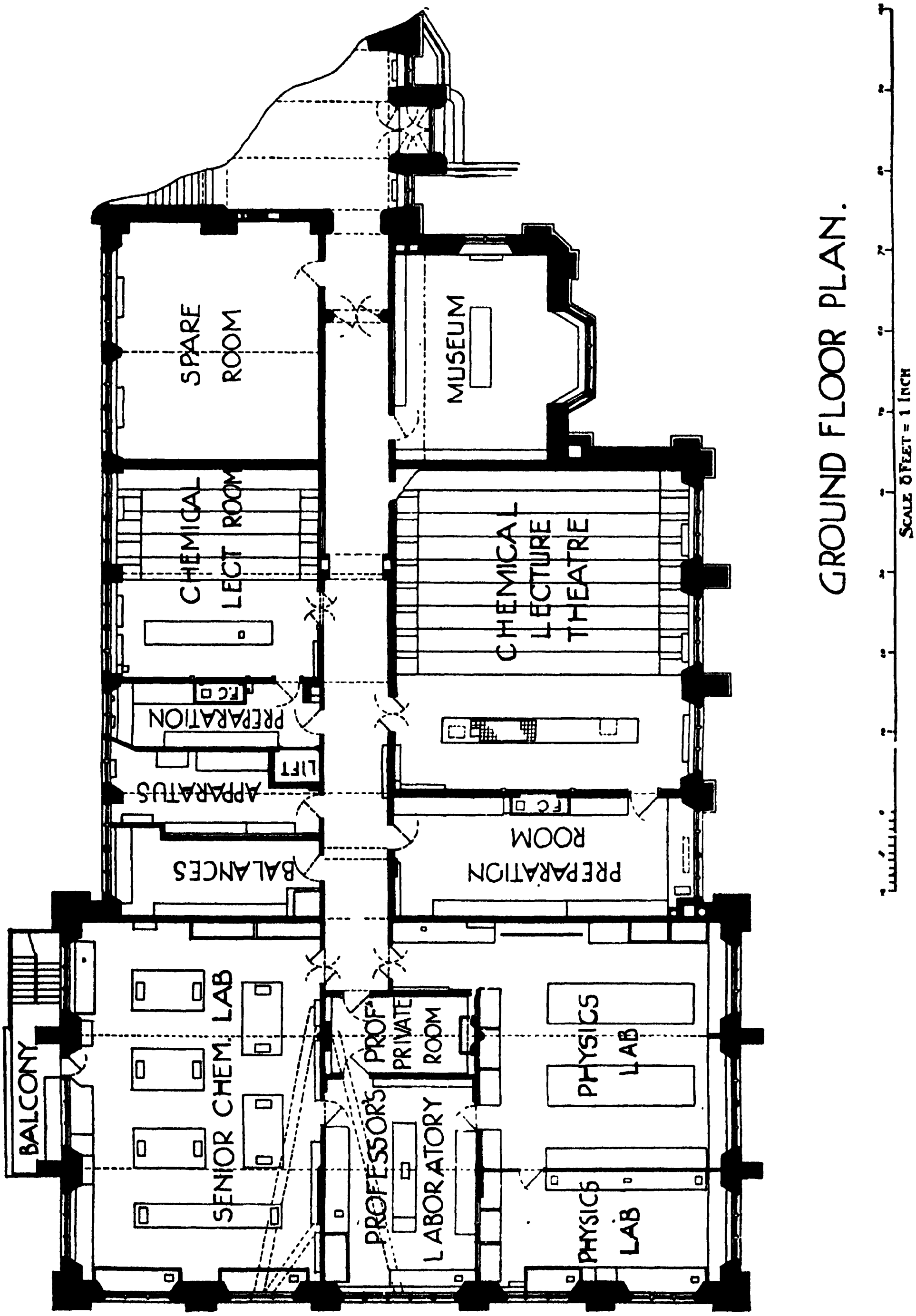
[1] These are called Water Analysis and Gas Analysis respectively on the plan, their use having altered since the block was made.



BASEMENT PLAN.

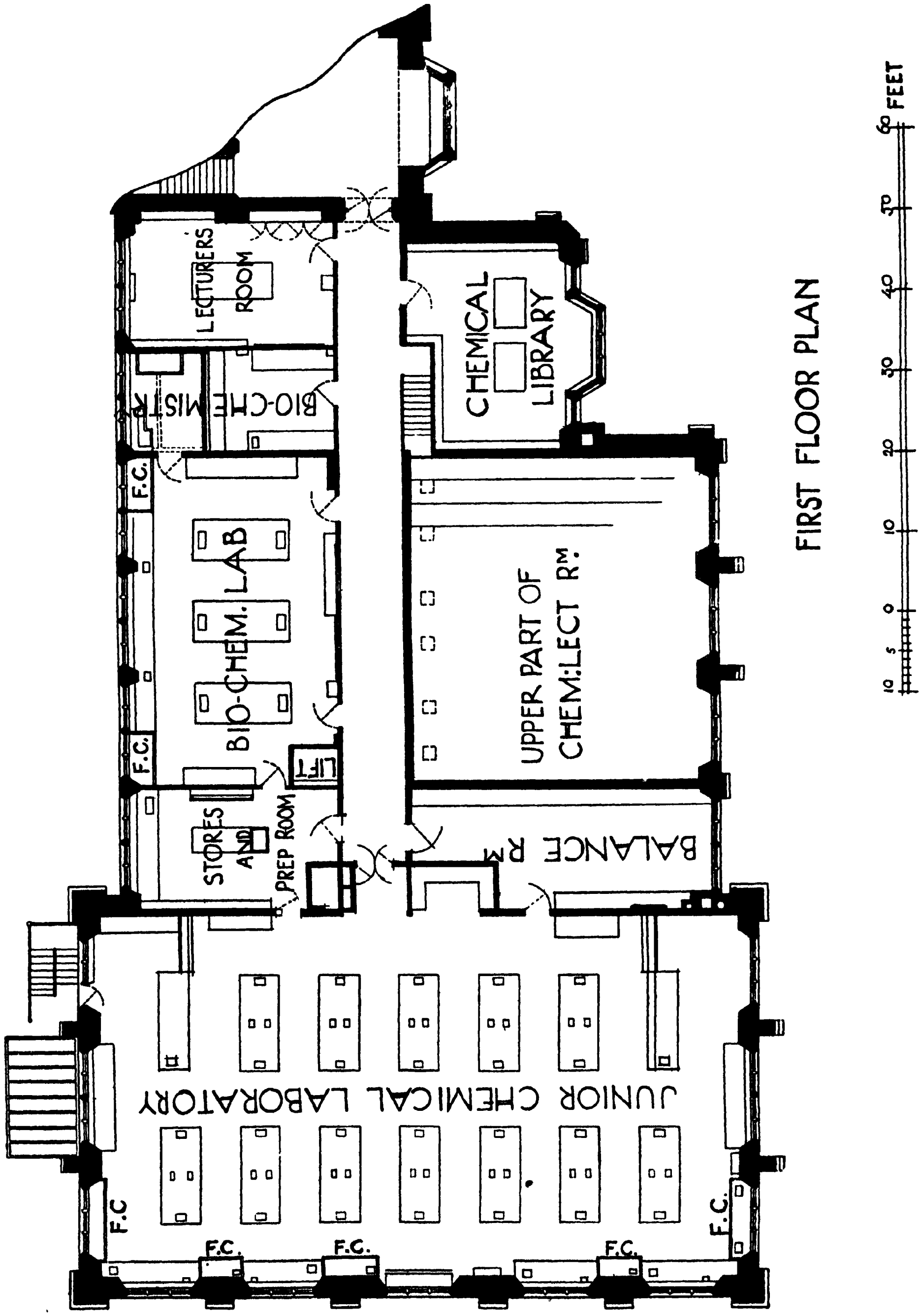
[*Oatley and Lawrence, F.F.R.I.B.A., Architects.*

FIG. 114.—Chemical Department, Bristol University.



[Oatley and Lawrence, F.F.R.I.B.A., Architects.

FIG. 115.—Chemical Department, Bristol University.



[Oatley and Lawrence, F.F.R.I.B.A., Architects.

FIG. 116.—Chemical Department, Bristol University.

The ground floor contains the main lecture theatre 40 ft. by 37 ft. which possesses a lecture table 24 ft. long. Adjoining is the preparation room and next to it two laboratories for electro and general physical chemistry, the larger of which contains the main distribution board, about 12 ft. by 9 ft., over the switchboard on the floor below. The professor's laboratory and small private room are placed between the physical and the senior organic laboratory. The latter, a room 45 ft. by 30 ft., possesses a useful balcony for open-air work with noxious gases. Combustions and closed tube work are also provided for in this room, which possesses a shower rose over a tiled floor space to meet possible accidents to students by fire. The partition walls between these laboratories are not constructional, which is arranged to admit of subsequent alterations should this prove desirable. Plate glass is used in the windows to prevent distortion. Other rooms on this floor include a second lecture theatre, a museum, which is provided with gas and water so that it can be converted into a laboratory should expansion render this necessary, and two dark rooms and a second year laboratory designated "Spare Room" on the plan.

The first floor contains the large elementary laboratory, a fine lofty room 80 ft. by 45 ft., in which the architects have made a special feature of the roof treatment. Here are 12 benches, 12 ft. by 5 ft., giving 4 ft. each for 72 students at one time, and at each end of the room near the inner wall are private benches for the demonstrators. These partial enclosures also serve as dispensaries. General benches and fume cupboards are placed in the windows and ovens and distilled water apparatus on the other side of the room. The alcove, shown on the plan, on this inner wall is for blowpipe work. The students' benches have draught flues and hoods. Adjoining the laboratory is a large balance room and a store and preparation room with a lift from the basement stores.

The bio-chemical laboratory[1] is fitted much as that for organic work and has two attached rooms for incubators and bacteriological work. A lecturer's room and small library complete the accommodation, which was designed for 200 students.

Electro-Chemical Laboratory, Liverpool University.

This building is of special interest as being wholly devoted to physical chemistry, and it is significant of our national appreciation of science that the

[1] Now third year laboratory.

only account of this institution appears in a German periodical.[1] The plans, **Figs. 117-20**, are from the drawings of the architects, Messrs. Willink and Thicknesse, F.R.I.B.A. The building forms a block about 80 ft. by 54 ft., consisting of a basement and three stories.

The basement contains on the left a large workroom with benches for six students, and next to it a room for heavy current experiments. The dynamo and accumulator rooms, with a dark room between them, are in the centre of this floor, and on the right is the heating plant.

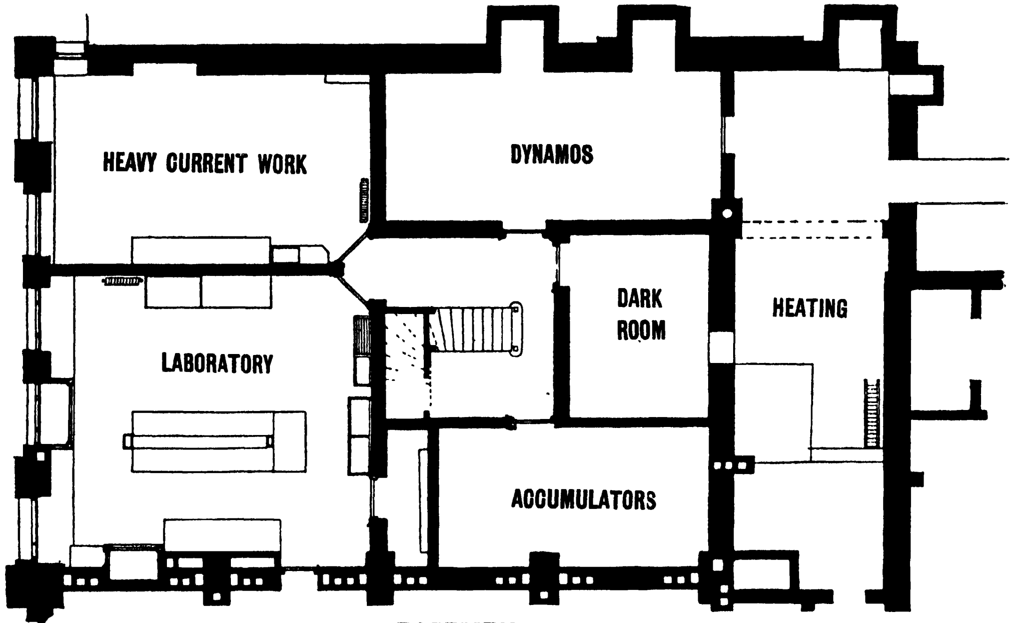
The ground floor contains a lecture theatre for 100 students, with a preparation room and laboratory assistant's room behind it, a dark room, a good library, a students' room, and a mechanics' workroom.

On the first floor is the large general laboratory, 45½ ft. by 29 ft., arranged for 25 students, with next to it a balance room and optical room, the former containing the electric distribution board. A research room, a lecturer's private laboratory, and an instrument room with a gallery, are also found on this floor.

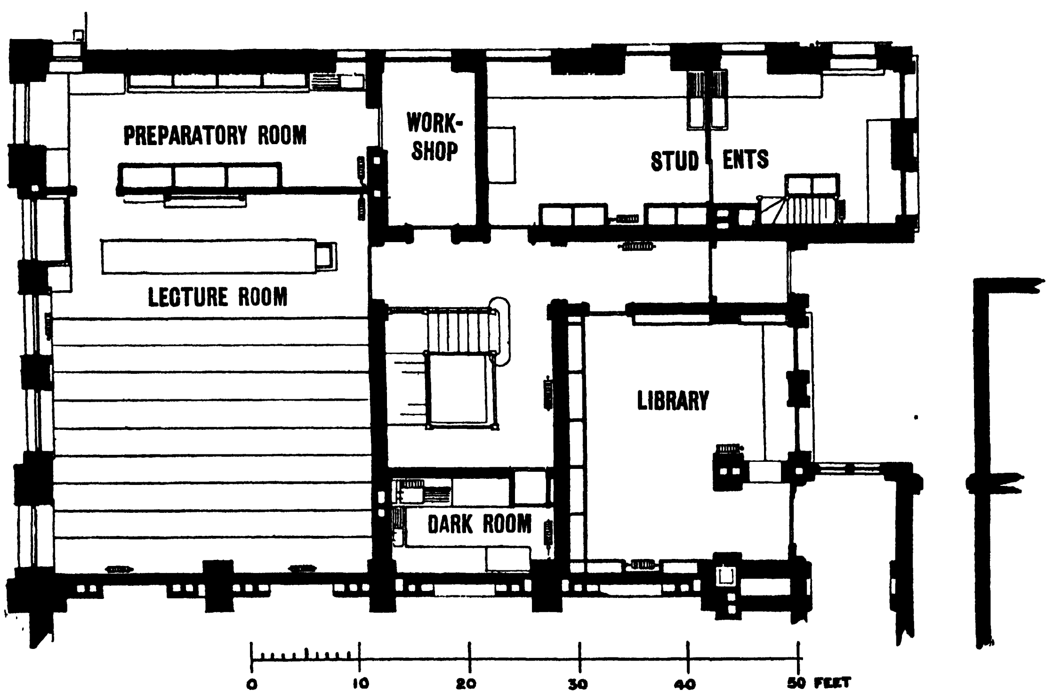
The second floor comprises four laboratories for advanced work, a balance room with distribution board for this floor, a large private laboratory and small sitting-room for the director. The lavatories are on the roof, which also accommodates a room for distillation, two stores, and open-air working places supplied with gas, water, drainage, and electric light.

Every workroom contains at least one fume cupboard. These fittings, built into the windows, are 5 ft. 11 ins. long and 3 ft. wide, surfaced in white glazed tiles, and are largely used as working benches. They are ventilated by special Bunsen gas jets. Vertical wood uprights, 1 ft. wide and about 3 ft. apart, are fixed to the walls for attaching apparatus. The research rooms have no fixed benches, but gas and water on the walls over narrow hinged tables. Lock-up cupboards on walls are provided in these rooms for students' private use. An illustration of the large laboratory has already been given on page 64. The benches measure 11 ft. by 5 ft. and are 3 ft. high, and serve either 4 students (2 on each side) or 2 if engaged in research. The tops are mostly of teak, but in some cases are pitch-pine. The drainage is effected by glazed channel pipes. Electric light is in use for illumination. Special ventilation by fans is arranged for the accumulator and heavy

[1] "Zeitschrift für Electrochemie," 1910. The author has to thank Prof. Doonan and the present Director, Prof. Lewis, for reference to this account, from which the details given are taken.

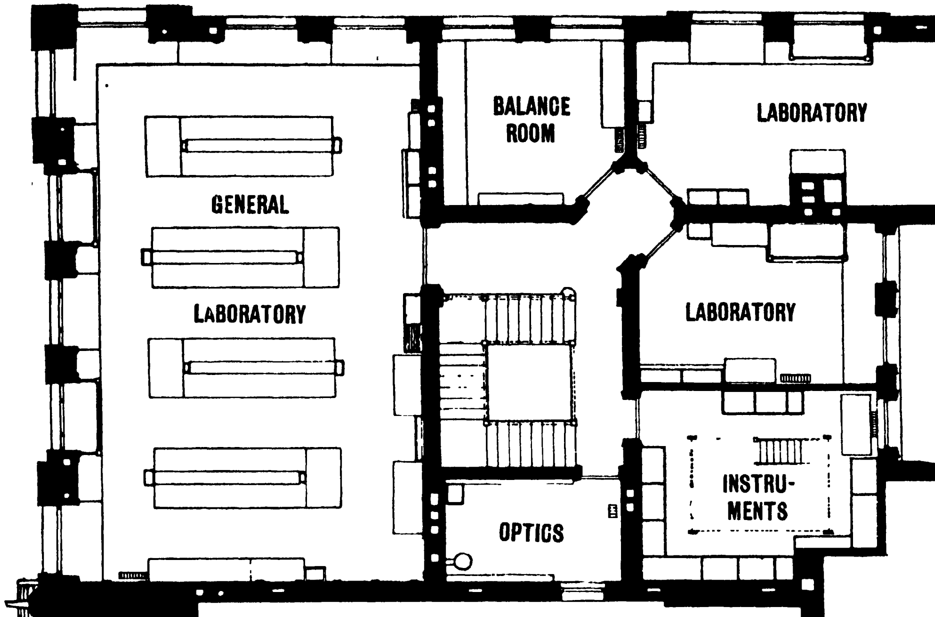


BASEMENT

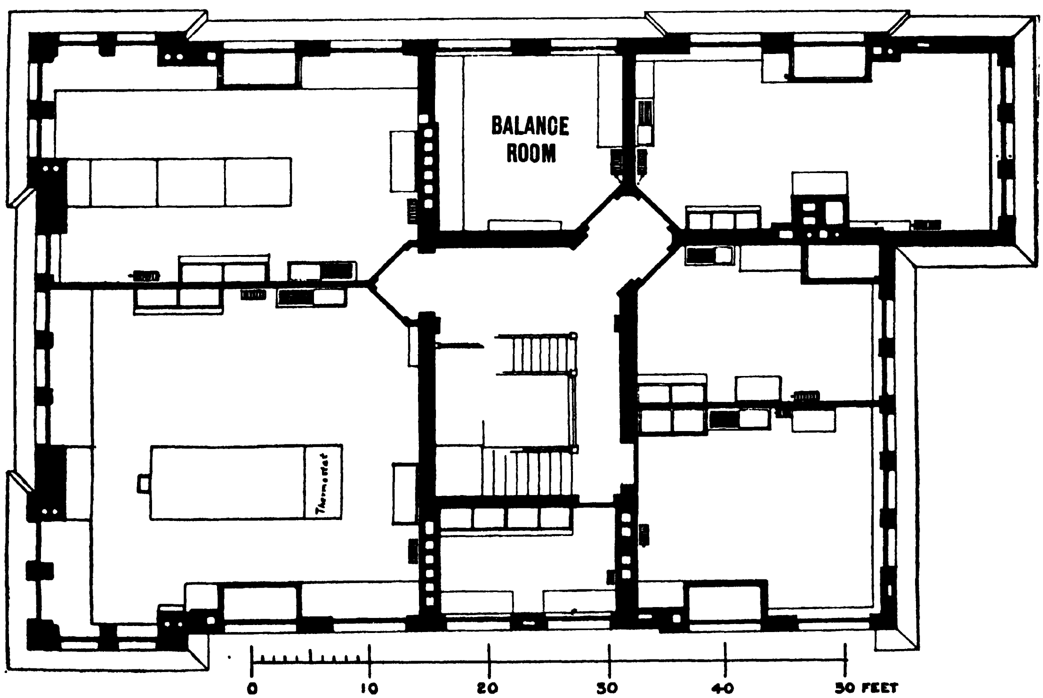


GROUND FLOOR

FIGS. 117 and 118.—Electro-Chemical Laboratory, Liverpool University.

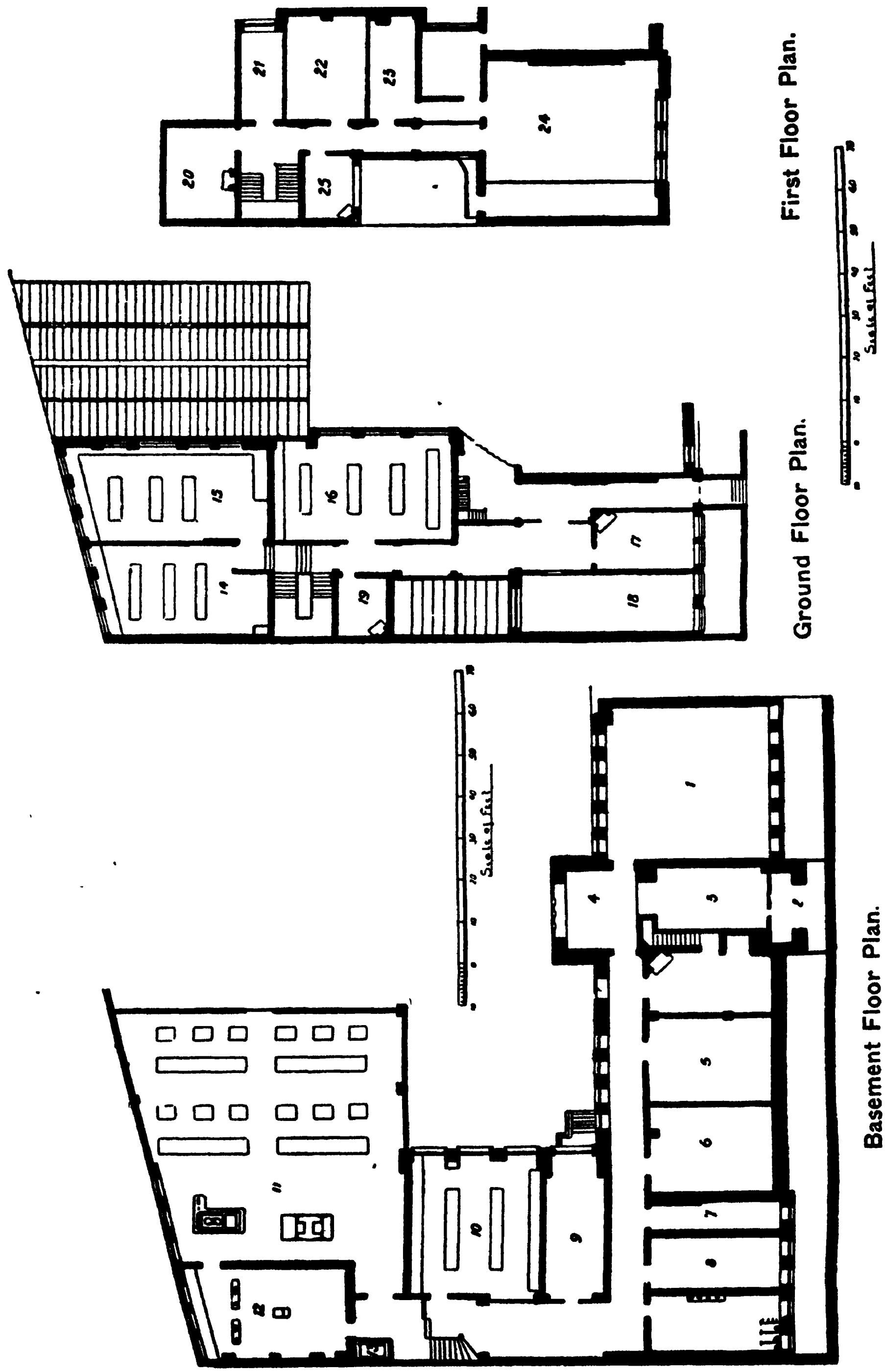


FIRST FLOOR



SECOND FLOOR

FIGS. 119 and 120. [*Willink and Thicknesse, F.R.I.B.A.*



Figs. 121 and 123.—Applied Electrical Laboratory, Liverpool University.

current rooms, and in the latter a large hood is provided connected to a flue, to catch the gases from the electric furnaces, from which hood 3000 c. ft. of air per minute can be extracted. The arrangements special to the electric service have already been described on pages 132-4. The building, fittings, electric installation, and apparatus cost respectively £9000, £4000, £3000, and £1200.

Applied Electrical Laboratory, Liverpool University.

For an account of this building and the plans shown, the author has to thank the University Registrar and Mr. Marchant, from whose paper on electrical testing these details are taken. The building comprises three floors, shown in **Figs. 121-3.** Following the numbers on the plans, in the basement (1) is a room 36 ft. square, set apart for delicate testing work as far as possible from sources of vibration;

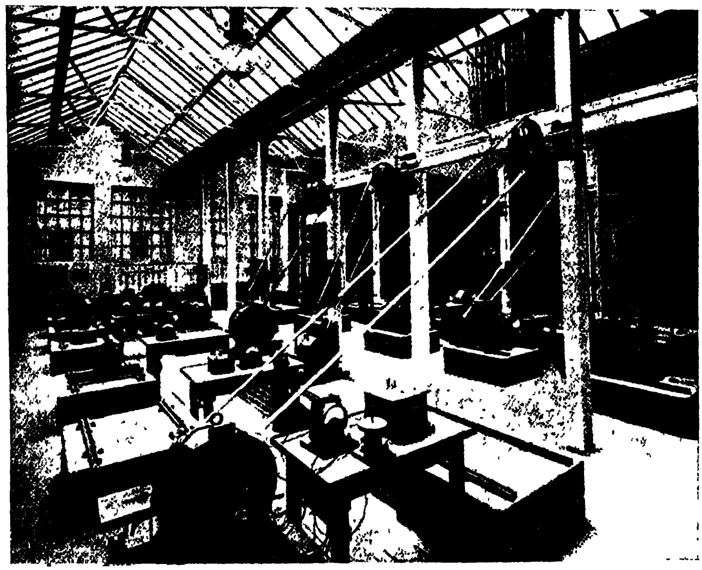


Fig. 122.—Dynamo Room (No. 11 on Plans), Applied Electrical Laboratory, Liverpool University.

(2) and (4) are respectively small battery and switchboard rooms, while (3) is used for testing lamps; (5) and (6) are research rooms; (7) is used for photometry; (8) is a room for testing iron; (9) a laboratory for high-tension work up to 20,000 volts; (10) is for alternating current work, contains five stationary transformers and accommodates 25 students; (11) is the dynamo room illustrated in **Fig. 122.** This room contains direct and alternating machines and in addition a gas engine charging set. The machine beds are 3 ft. 9 ins. wide, and 2 ft. high, and this raising is found a great convenience. Small tables are also provided for experimental work

with connections to the distribution board at the end of the room. On the ground floor, rooms (15) and (16) are for elementary students, the latter for the more delicate instruments, chiefly galvanometers; (17) and (18) are the professors' rooms, while (19) is a small library. On the first floor (24) is a lecture theatre which seats 130 students, the other rooms being special laboratories, class and preparation rooms.

Botany School, Cambridge University.

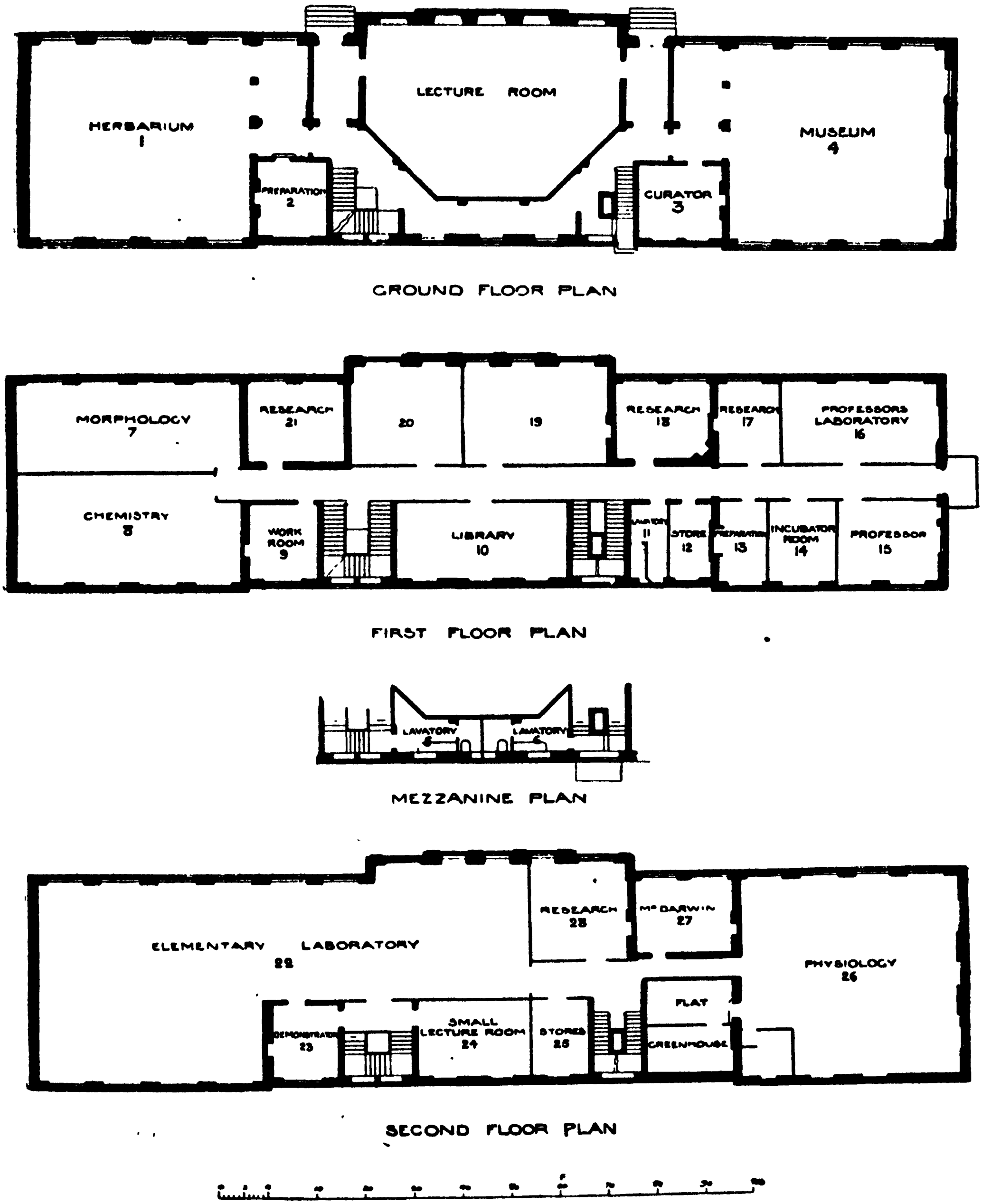
In connection with buildings described at Cambridge, the author's special thanks are due to his friend, Mr. Arthur Hutchinson, of Pembroke, for his kindness in arranging facilities for inspection of the laboratories and obtaining plans and descriptions which were only in private circulation. As regards the Botany School, thanks are also due to Prof. A. C. Seward for an opportunity of inspecting this building under his personal guidance, and to the University Press Syndicate for the use of the illustrations, Figs. 124-6, from the designs of the architect, Mr. W. C. Marshall. The building forms a rectangular block, 200 ft. by 40 ft., consisting of three floors and a basement. The basement is occupied in the centre by the lower part of the large lecture theatre, behind which are store rooms and a workshop, and the rest of this floor is taken up by the heating plant and fuel.

On the ground floor the lecture theatre above referred to occupies 52 ft. by 35 ft. and has raised seating for 200 students. On the left is the herbarium, 45 ft. by 39 ft. 6 ins., lighted on the north and south, the collections being arranged to form bays, with tables for reference work between them, and adjoining is the curator's room.[1] Similarly arranged and of the same size, but lighted on three sides, is the museum, with its curator's room, on the other side of the lecture theatre.

The first floor contains on the left the chemical laboratory with a fire-proof floor, which is equipped with ordinary double benches with drawers but without lockers. The morphological laboratory is fitted with a continuous window bench and a parallel one behind it. Gas is provided in the former and three sinks are placed in different positions round the walls. The back wall of the room is wholly devoted to shelving for the storage of specimens in spirit. At one end of the room is a large wall blackboard.

In the centre of this floor is the library, and on the other side of the corridor, two private working rooms for the staff, numbered 19 and 20, while on the

[1] Preparation room on the plan.



FIGS. 124 to 126—Botany School, Cambridge University.

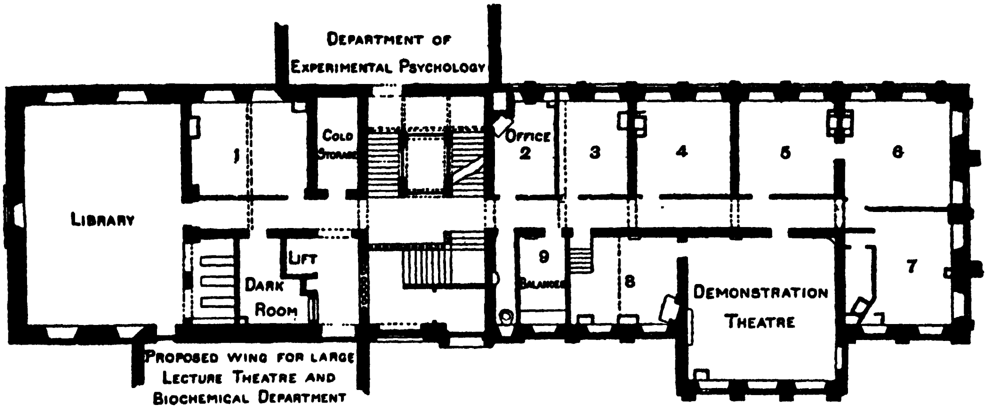
right research rooms and Prof. Seward's private room and laboratory find a place in addition to store and preparation rooms and accommodation for an incubator which stands on a low stone table under a brick hood provided with a flue. The projection shown on the plan at the end of the corridor is a small greenhouse.

The second floor is devoted to a very large elementary laboratory on the left, 100 ft. by 40 ft. at its widest part. The room has places for 150 students at plain deal benches, 2 ft. 10½ ins. high, without drawers or cupboards. At the end of the room is a range of small lockers. An illustration of this room has been given on page 97. A demonstrator's room, small lecture room and store adjoin this laboratory. At the other end of this floor is the physiological laboratory, a room 40 ft. by 46 ft., which contains deal window benches of the same height as those in the elementary laboratory, a combustion bench, a table for mercury experiments with raised edge, and a small greenhouse 3 ft. by 2 ft., placed on a table. Provision is made for galvanometers, and a small part of the laboratory is partitioned off as a dark room. Both high and low-pressure water are supplied to this room, and off the flat adjoining it is a greenhouse, sunk to this floor level so that it is not exposed to the sun. On the roof is another greenhouse and a large flat for experimental work in the open air.

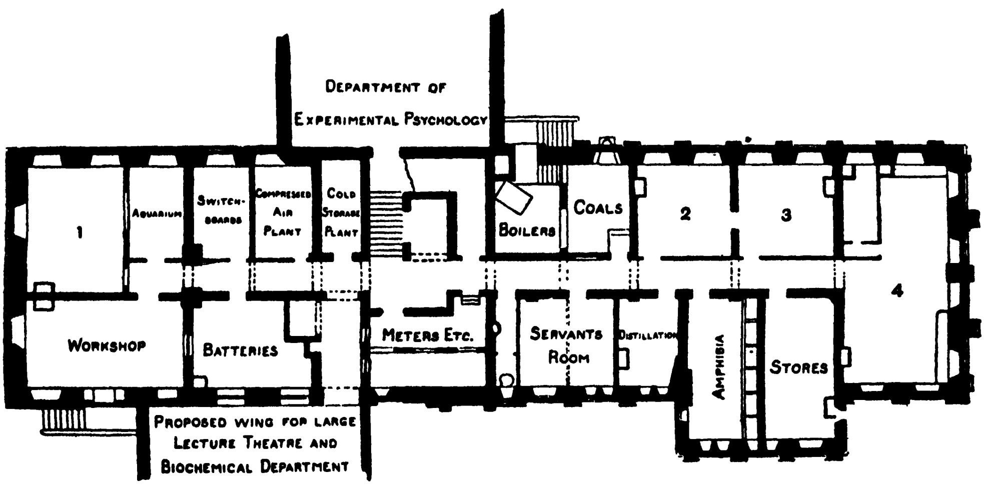
School of Physiology, Cambridge University.

Through the kindness of Prof. Langley and his staff, the writer was enabled to inspect this building, which was opened in 1914. It forms a rectangular block, 165 ft. by 43 ft., consisting of a sunk ground floor and four upper floors, plans of which are shown in **Figs. 127-31** through the courtesy of the Cambridge Press Syndicate, and of Sir Thomas Jackson, the architect. The ground floor contains four research rooms (numbered 1 to 4) devoted to thermo- and electro-physiological experiments, three of these rooms being placed as far as possible from running machines, since much galvanometer work is required here. The central rear rooms are occupied by the compressed air plant, centrifuge, cold storage and heating plant, while on the frontage is a good repairing shop, battery room, store, and a room containing concrete tanks for preserving live amphibia, which have been already described (p. 107).

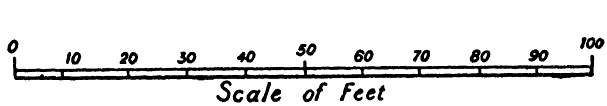
The first floor contains a good library, 38 ft. by 28 ft., with stock room,



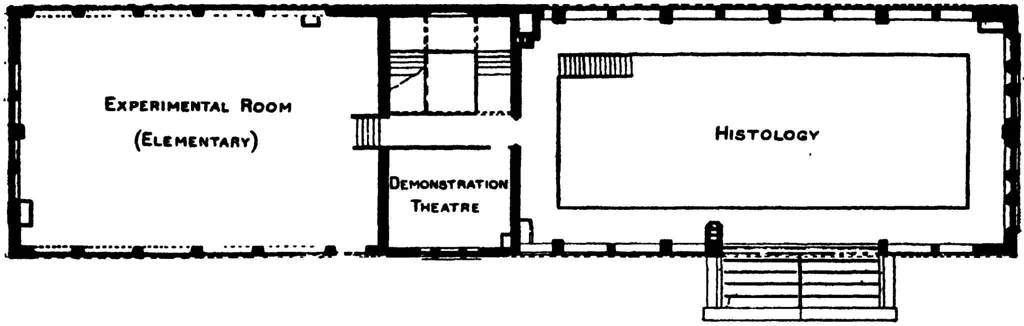
FIRST FLOOR



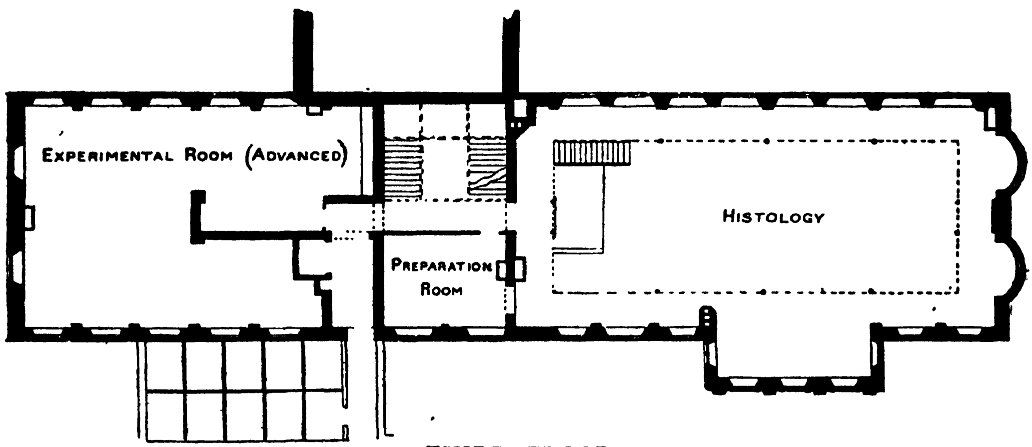
GROUND FLOOR



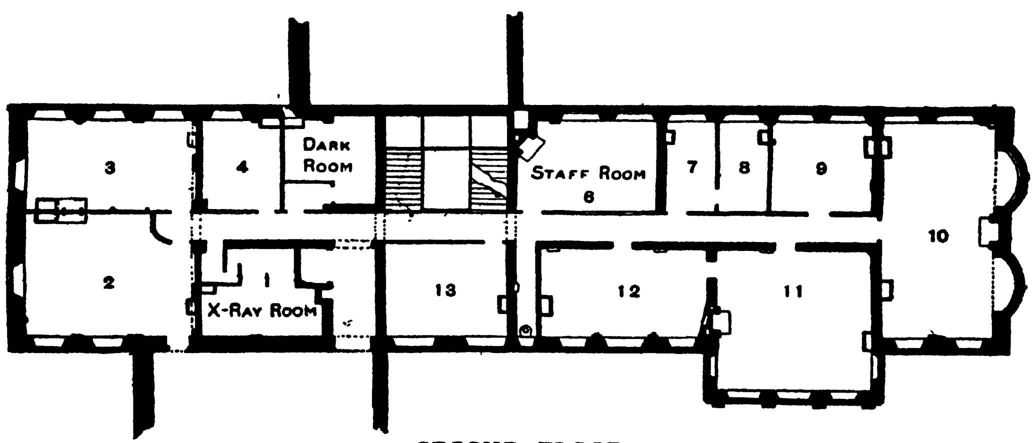
Figs. 127 and 128.—Cambridge University, School of Physiology.



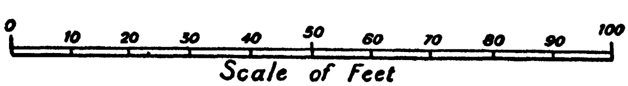
FOURTH FLOOR



THIRD FLOOR



SECOND FLOOR



FIGS. 129 to 131.—Cambridge University, School of Physiology.

six private research rooms, dark room, balance room, a demonstration theatre to hold 80, a room adjoining for the lecturer, and, at the angle of the building, a room in which a kinematograph is worked for projections in the theatre. The research rooms are fitted with wall benches and sinks with hot and cold water, pendulum contact clocks supplied with current at 110 and also 4 volts, and space is left for operating, and other loose tables and large live boxes. The theatre has continuous staged desks and a heavy plain lecture table, devoid of drawers and cupboards. The blackboard used in this room is of the canvas roller type.

The second floor is devoted almost wholly to research. The rooms numbered 7, 8, 9, are fitted with pumps, shaking machines, and aspirators for respiration experiments. No. 10 is the professor's laboratory and No. 11 is designed for neurology, which study involves section cutting and electrical stimulation. An X-ray room and dark room for vision experiments complete this floor.

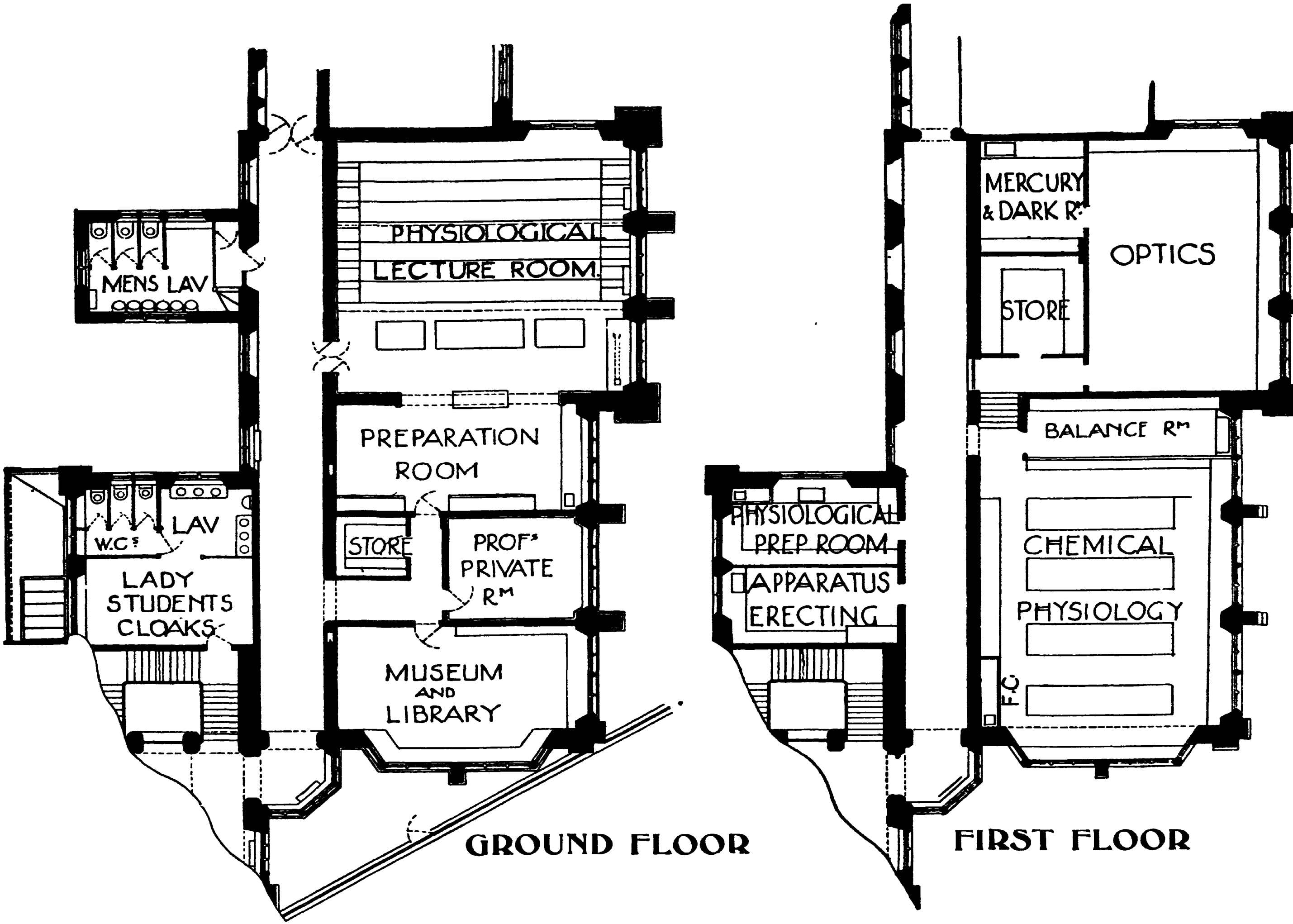
The third floor comprises two large laboratories, that on the left is devoted to advanced work involving drum records, detailed reference to which has been made on page 106, and window benches are also provided for histology. The histological laboratory, a fine room 80 ft. by 40 ft., possesses in all 166 places, including the gallery, which forms the fourth floor of this wing, and is also fitted for students' work. It has side windows and a saw roof light, concealed by tiled slopes all round. The students work at continuous benches 2 ft. 9 ins. wide and 2 ft. 10 ins. high, and are given a bench length of 2 ft. 2 ins. Each place has two drawers 17 ins. by 13 ins. by 4 ins. deep, and between two students is a warming plate 9 ins. by 4 ins. with a gas jet. A large platform and blackboard is provided near the access. Off this laboratory is a preparation room with benches and a large sink for the laboratory assistant.

On the top floor, not occupied by the histological gallery, is a large laboratory 60 ft. by 42 ft. where work as described for the room below, but of an elementary kind, is carried out. The arrangements for the drums are similar, the space given for each student being, however, only 2 ft. 9 ins., which admits of accommodation for a class of 46. Adjoining this room is a small theatre with curved raised staging for dissection demonstrations, on the back rows of which the students stand. A section through this staging has been figured on page 108. A small plain wooden operating table about 3 ft

4 ins. high, a lead-lined sink 18 ins. square, a stone corbel for a galvanometer, gas, and a 10 ampere plug on the wall, comprise the equipment of this room.

Physiological Department, Bristol University.

The chemical department of this university has already been described in this chapter, and physiology is provided for in a part of the same block, the broken line on the plans representing the connection between the two. The author has to thank Prof. A. F. Stanley Kent for an opportunity of inspecting his department and for the information here given, and the architects, Messrs. Oatley and Lawrence, for contributing the plans, **Figs. 132-4.** Owing to the slope of the site, the basement area is confined to store rooms and lavatories with the exception of a microphotographic room and dark room adjoining the constant temperature cold store and incubator room, which are, strictly, in the wing devoted to chemistry, and appear in these plans on page 171. The ground floor contains the lecture theatre, about 36 ft. square, floored in terrazzo, with a preparation room thrown into it behind. Prof. Kent's arrangements for diagrams, lantern, and his movable lecture table have already been referred to, and illustrated on pages 45 and 48. Next the preparation room is his private room and a small store for lecture purposes, and, adjoining, is a combined museum and library, devoted, as far as the museum is concerned, chiefly to specimens required for lecture purposes. On the first floor is a large optical room arranged for the study of special senses, gas analysis, and photographic work, and adjoining is a laboratory for chemical physiology, about 30 ft. by 40 ft., with a balance room, also available for students, next the optical room. This laboratory is fitted with double benches, equipped with gas, water, and electricity, and wood V-shaped drains are used in these benches as in the chemical department. On a tiled bench provision is made for combustions, drying ovens and still, blowpipe work and an incubator. A small centrifugal machine is also available. The benches are furnished with lockers and the room accommodates 40 senior or 70 elementary students at one time. On the other side of the corridor is a preparation room and apparatus erecting room, which are also available, if necessary, for individual advanced work. The second floor contains a fine histological room, 45 ft. by 36 ft., with a gallery, excellently lighted by a saw roof glazed towards the north, and also



GROUND FLOOR

FIRST FLOOR

[Oatley and Lawrence, F.F.R.I.B.A., Architects.

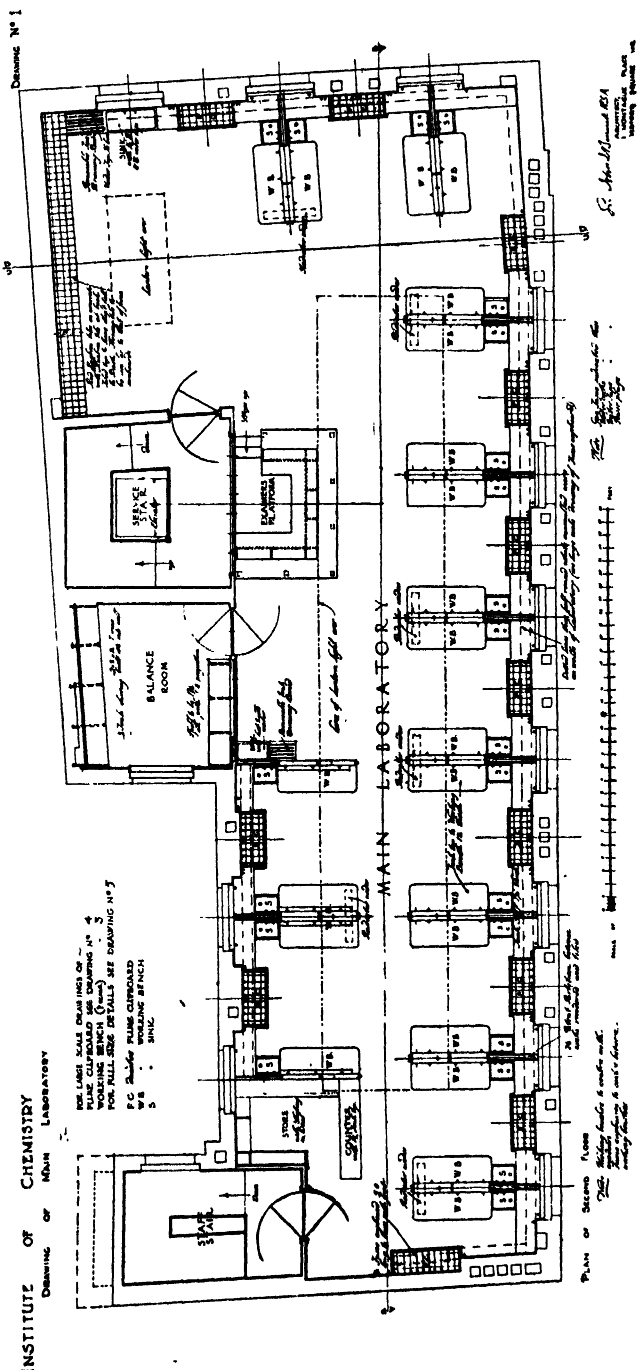
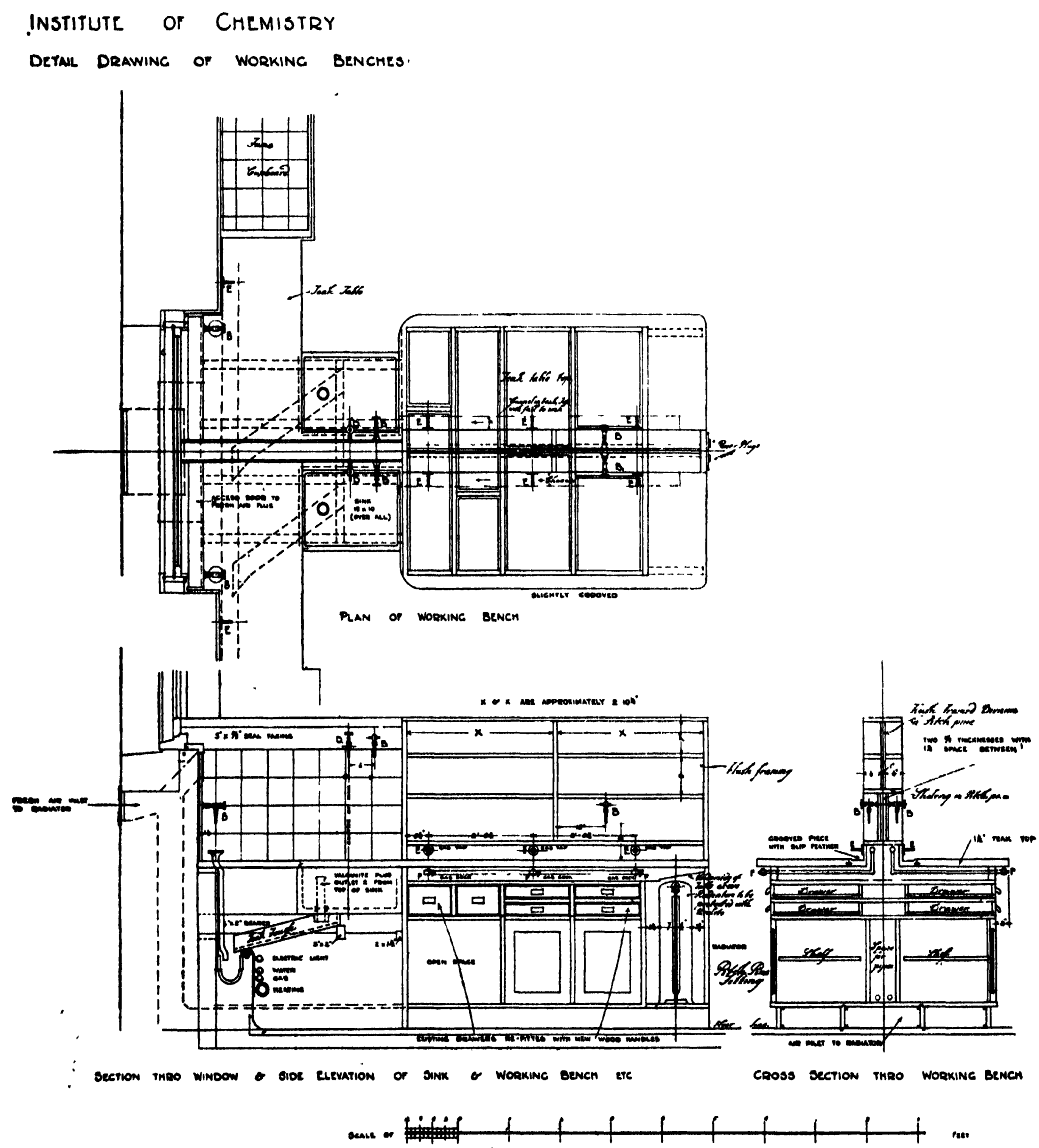


FIG. 135.—Institute of Chemistry, London.



Sir J. J. Burnet, F.R.I.B.A., Architect.

FIG. 136.—Detail of Working Bench, Institute of Chemistry, London.

by end windows. A good demonstration table on a raised platform is provided facing the students, who work at a series of long benches. For night work, inverted incandescent gas burners are used for microscope illumination. On the west wall is a tiled bench accommodating incubators. The room seats 50 to 60 students, but this number can be greatly increased by the use of the gallery, 6 ft. wide, provided round three sides. Over the chemical laboratory referred to on the floor below, is a physiological laboratory, which contains

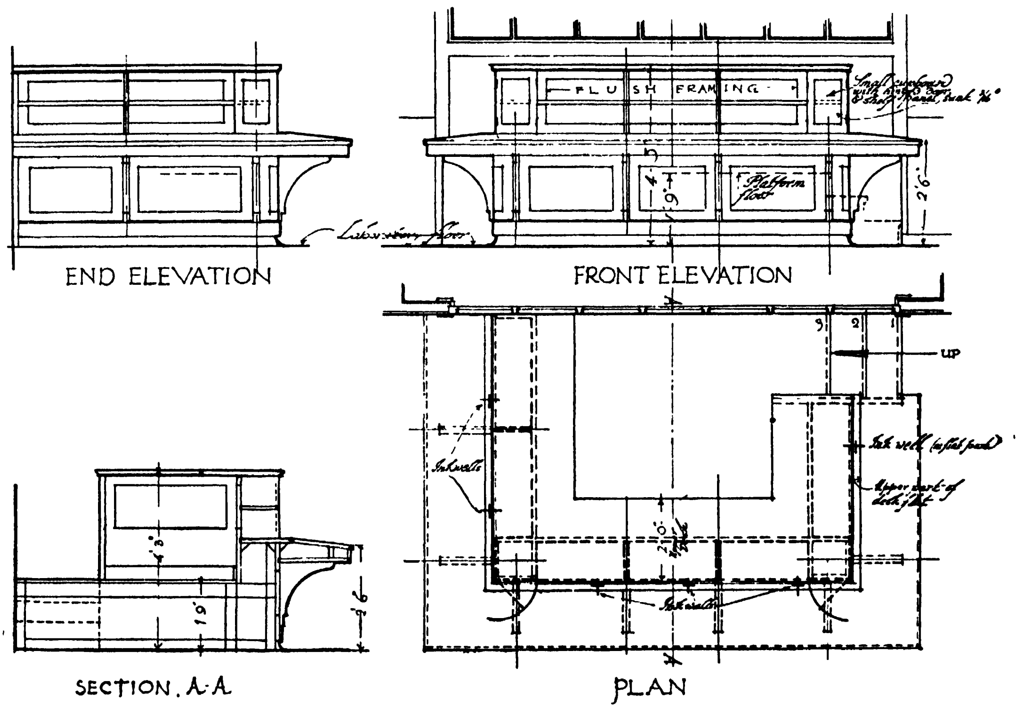


FIG. 137.—Examiner's Table, Institute of Chemistry, London.

window benches for motor-driven recording drums, while small tables are used in the centre of the room for delicate apparatus. Overrunning part of the chemical department below are preparation and research rooms, including the professor's laboratory, which has rounded angles to the walls and an impervious floor to enable the room to be washed down with a hose. Alternate current at 105 and 210 volts, and direct current at 72 volts, is provided. Finally, a demonstration theatre for operative work with steeply raised tiers is placed in a central position in this wing.

The Institute of Chemistry, London.

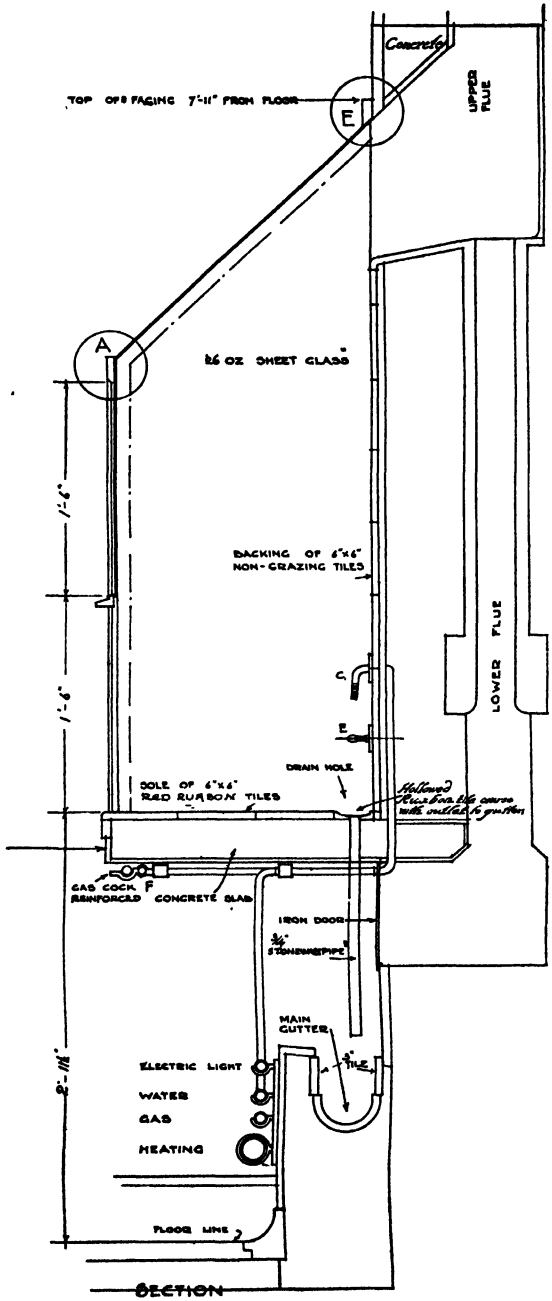
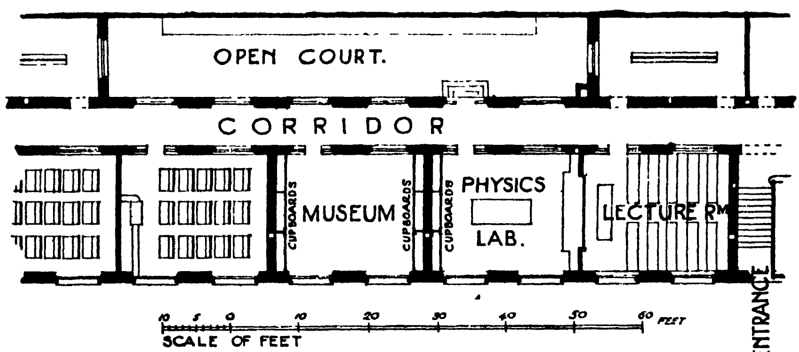


FIG. 138.—Section through Fume Cupboard, Institute

This building, erected in 1915, forms an interesting recent addition to our chemical institutions, though arranged solely for examination purposes, and therefore somewhat specialized as regards its objects. The illustrations, **Figs.** 135-8, are from the drawings of the architect, Sir John J. Burnet, F.R.I.B.A., R.S.A., who has kindly made this contribution. The building consists of a basement, subground, ground, first and second floors. The first three are devoted to caretaker's quarters, cloak rooms, offices, council and committee rooms, and a library, the two upper floors containing the laboratory accommodation. The first floor comprises metallurgical, gas, physical, and biological laboratories, also a dark room and examiners' and assistants' rooms. The main laboratory, of which a plan is shown in **Fig.** 135, occupies the whole of the second floor. This room, 90 ft. long and 25 to 35 ft. wide, is arranged in bays with a bench for each student, who has his own sink, a small wall bench, and the use of a large fume cupboard shared with his neighbour working at the adjoining bench. The whole of the

walls above the floor. The bench tops are 1½ inch teak, the drains glazed channels, the reagent shelves of wood, and the fume cupboard bases of red tiles. Draught is provided by gas jets to separate flues. **Fig. 136** shows a plan, elevation and section, of one of the working benches and its surroundings, and **Fig. 137** the examiners' platform provided externally with shelves, and a broad desk for using works of reference. **Fig. 138** shows a section through a fume cupboard, the flues to which are carried down so that the gas is lighted from beneath. An effort has been made to exclude woodwork from the interior of these cupboards, and in the case of those in the form of hoods having a fixed glass curtain open below, the glass to the sides is bedded on the frames and runs right up to the front curtain and roof.

The laboratory contains, in addition to the fittings described, a long tiled bench for combustions, and a chemical store arranged with a counter to act as a dispensary. Off the room, centrally situated, is a balance room.



[*M. Choret, Architect.*

FIG. 139.—Science Rooms, College de Jeunes Filles, St. Germain-en-Layes.

SECTION III. RECENT FOREIGN DESIGNS.

Science Rooms, College de Jeunes Filles, St. Germain-en-Layes.

This example of the arrangements for science teaching in a girls' school is kindly contributed by M. Choret, the architect. The plan, **Fig. 139**, shows a lecture room, laboratory, and on the other side of the corridor, a long open court for experimental work. The lecture room has a raised staging on which are desks with separate seats. Behind the lecturer's table, which has

a sink and mercury bath and a 25 ampere supply, is a large opening into the laboratory beyond, over which slides the blackboard. The laboratory has the usual necessary fittings for elementary work. An interesting feature is the use of "lave emaillée" for the table tops; this is shown in Fig. 140, which illustrates the end of the laboratory adjoining the lecture room, and is contributed by MM. Flicoteaux et Cie,[1] the makers of this material. In the court the pupils work in pairs, and accommodation with ample supplies of water and gas is arranged for 15 such groups. A large glazed hood covers the working place as a protection from the weather. This rather novel use of what would presumably be in any event a necessary area for light and ventilation is worthy of notice.

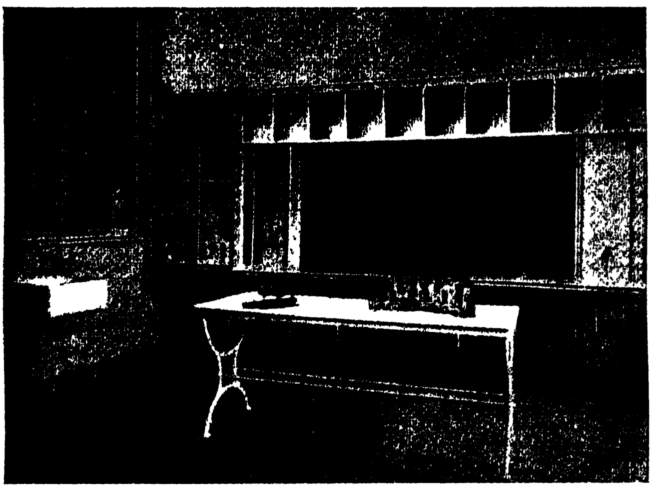
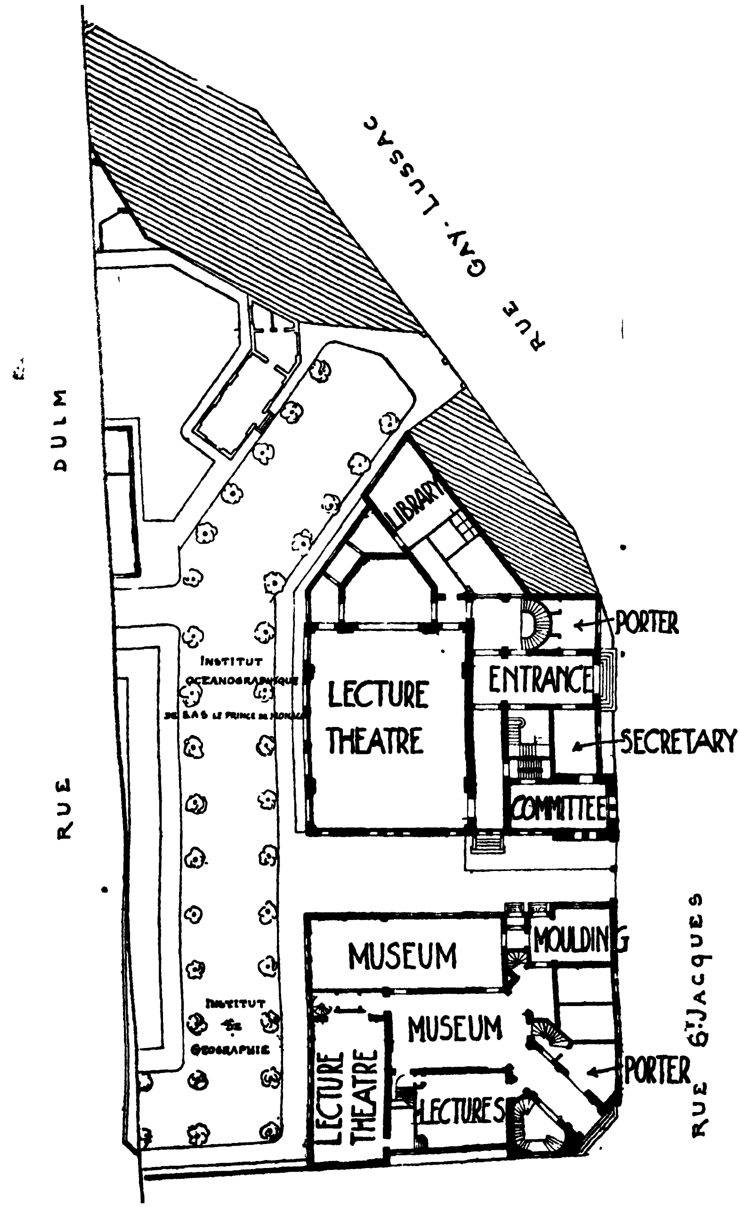


FIG. 140.—Physics Laboratory Showing Opening to Lecture Room.

Institute of Chemistry, Paris.

The ground plan of the Institute of Chemistry, Paris, with the adjoining Pasteur and Oceanography Institutes, Fig. 141, has been kindly contributed by the architect, Mons. H. P. Nénot. This building is only now in course of erection, hence no detailed account of its arrangements is available. The scheme shows a fine symmetrical plan on a lavish scale as regards architectural treatment, and the laboratories, each nearly 70 ft. by 40 ft., are arranged for the different years of the students, in addition to which an elementary laboratory is provided for general work in the centre of the block. The lecture theatres, entirely enclosed by corridors and top lighted, are placed in the centre of the other working rooms at each end of the block with their subsidiary rooms adjoining.

[1] 83 Rue du Bac, Paris.



[*H. P. Nénot, Architect.*

[*To face page* 192.

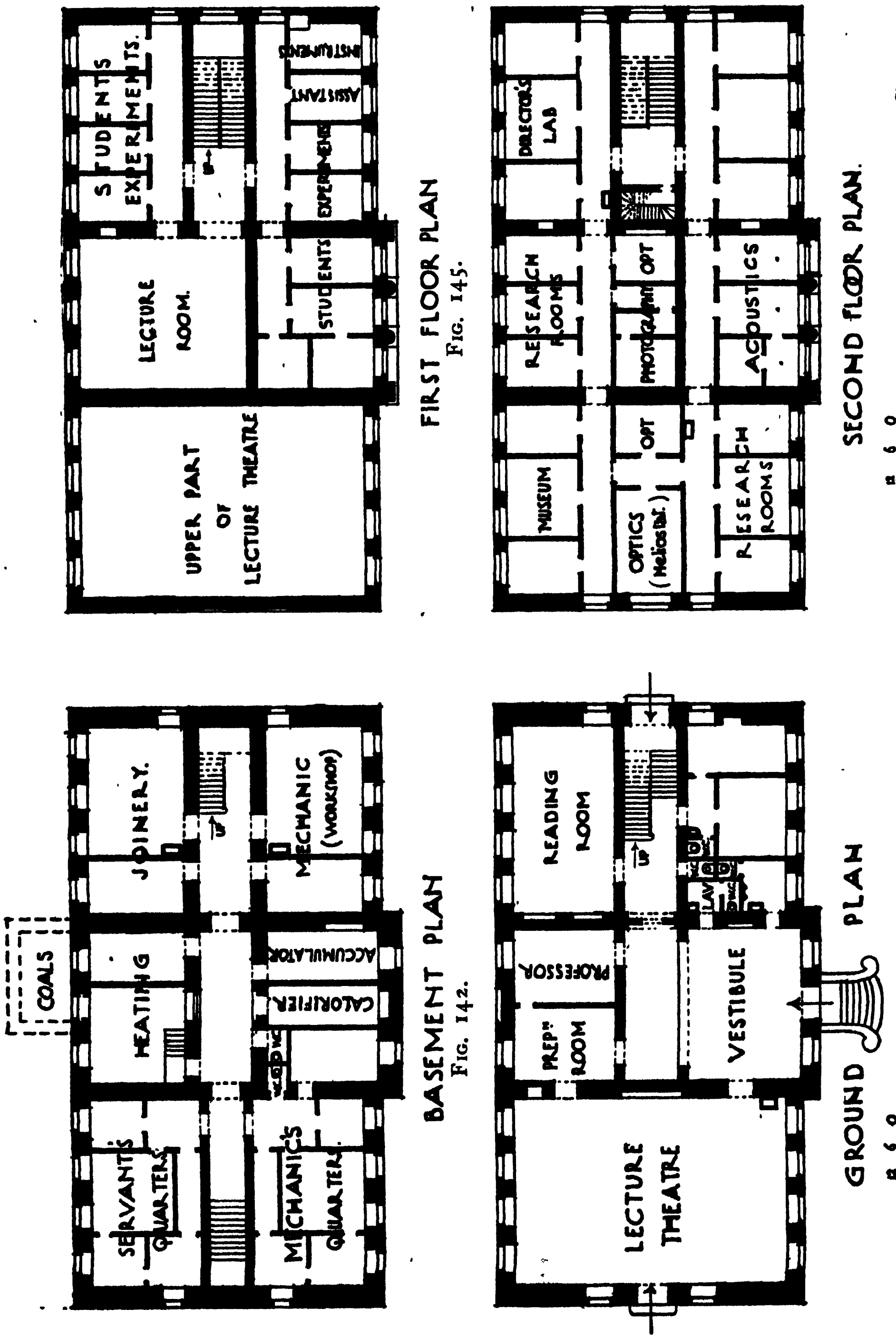
The Psychological Institute, Moscow University.

For an account of this institution, erected in 1912, the author is indebted to the kindness of Prof. Sergius Glinka of Moscow University, and to the architect. Psychology, which deals with the connection between the mind and consciousness, as evidenced through the senses, has not been specifically dealt with in these pages because its material equipment is still in the early experimental stage, but this strongly resembles that demanded by vertebrate physiology with which this study is usually associated. The building, the plans of which are given in **Figs. 142-7**, is a rectangular block of about 100 ft by 50 ft., consisting of three floors and a basement. The left wing of the basement, **Fig. 142**, is devoted to servants and the mechanics' quarters, the centre to the heating plant, calorifier, and accumulator plant, while on the right is a joinery workshop at the rear, and a mechanics' shop, illustrated in **Fig. 143**, on the frontage.

On the ground floor, **Fig. 144**, is the large lecture theatre, 49 ft. by 32 ft., running through two stories, entered by the students from the large vestibule, and by the professor from his private room through the adjoining preparation room on the other side of the corridor. On the right, administrative rooms occupy the front, and a reading room, 34 ft. by 19 ft., the rear portion of this floor.

The first floor, **Fig. 145**, is devoted to ten rooms about 14 ft. by 8 ft., two of which are for the assistant and for instruments, and the others for individual experimental work, for which there are in addition two smaller rooms. One of these smaller rooms, which is windowless, has double walls and is used for acoustics. The larger central room, further illustrated in **Fig. 146**, is a small lecture room and contains cupboards for physical apparatus.

The second floor, **Fig. 147**, is devoted to rooms for research by the staff. The four on the centre of the frontage provide for acoustic work, one being double walled with a lining of cork. Behind these rooms are two photographic dark rooms, and next the stairs a room devoted to optical work, to which subject two more rooms in the centre of the left wing are also allocated, that with a window being used for a heliostat. The centre room in the left wing at the rear is a museum, and that of similar size and position in the right wing is the director's laboratory.



FIRST FLOOR PLAN

Fig. 145.

SECOND FLOOR PLAN.

Fig. 147.

BASEMENT PLAN

Fig. 142.

GROUND PLAN

Fig. 144.

Institute of Psychology, Moscow.

The Bio-Anatomic Institute, Moscow.

Though somewhat beyond the scope of this book, a brief description of this building, devoted to women students qualifying for medical and surgical diplomas, is included as a further interesting Russian example, again kindly contributed by Prof. Glinka and the architect. The building consists of a slightly sunk ground and two upper floors, and is shown in **Figs. 148-50.** On the extreme left of the ground floor, **Fig. 148,** is an entrance for apparatus, a transformer room and porter's office, while the semicircular room at the rear is a large dissecting room with a cloakroom, and the boiler room adjoining, and on the other side of the corridor are preparation and store rooms for chemicals. The students' entrance is at the rear of the building on the other side of the dissecting room. The other rooms on this floor are servants' quarters, kitchens, photographic and refrigerating rooms, stores, and refreshment rooms, while a mortuary and

FIG. 143.—Mechanics' Shop.

FIG. 146.—Small Lecture Room.

chapel also find a plaće here. On the first floor, **Fig. 149**, an anatomical museum is arranged, under the upper tiers of the steeply raised seating of the semicircular demonstration theatre, shown completely on the floor above. The space in front is a large vestibule. The small rooms on the right are for botany, physiology, geology, chemistry, and physics, and also include a reading and waiting room, while on the extreme right is the large chemical laboratory with its adjuncts on the frontage. On the second floor, **Fig. 150**, in front of the large demonstration theatre, which possesses both a central dissecting table and a lecture

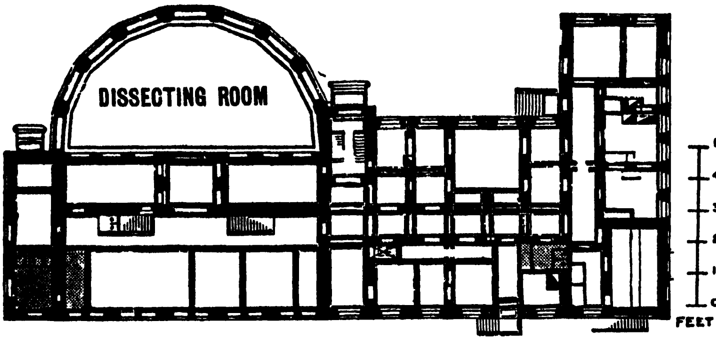


Fig. 150.—SECOND FLOOR

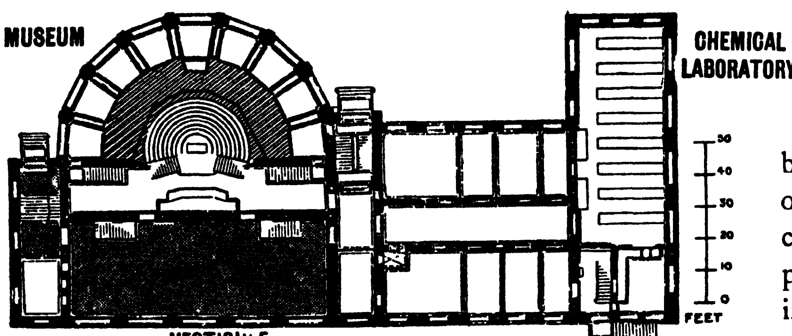


Fig. 149.—FIRST FLOOR

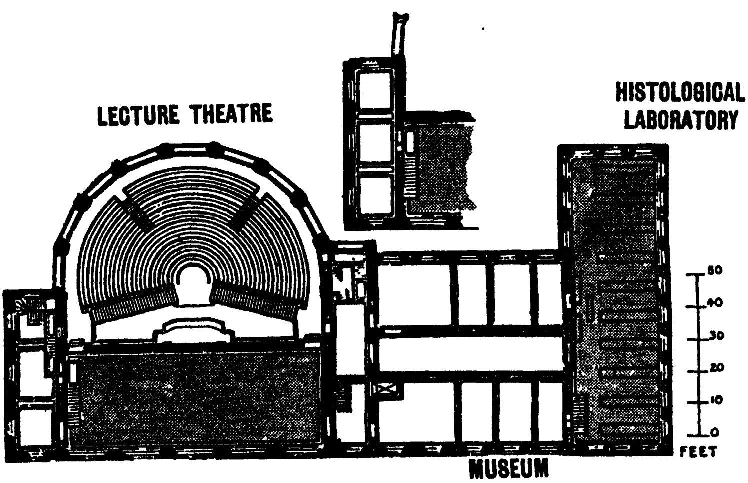


Fig. 148.—GROUND FLOOR

The Bio-Anatomic Institute, Moscow.

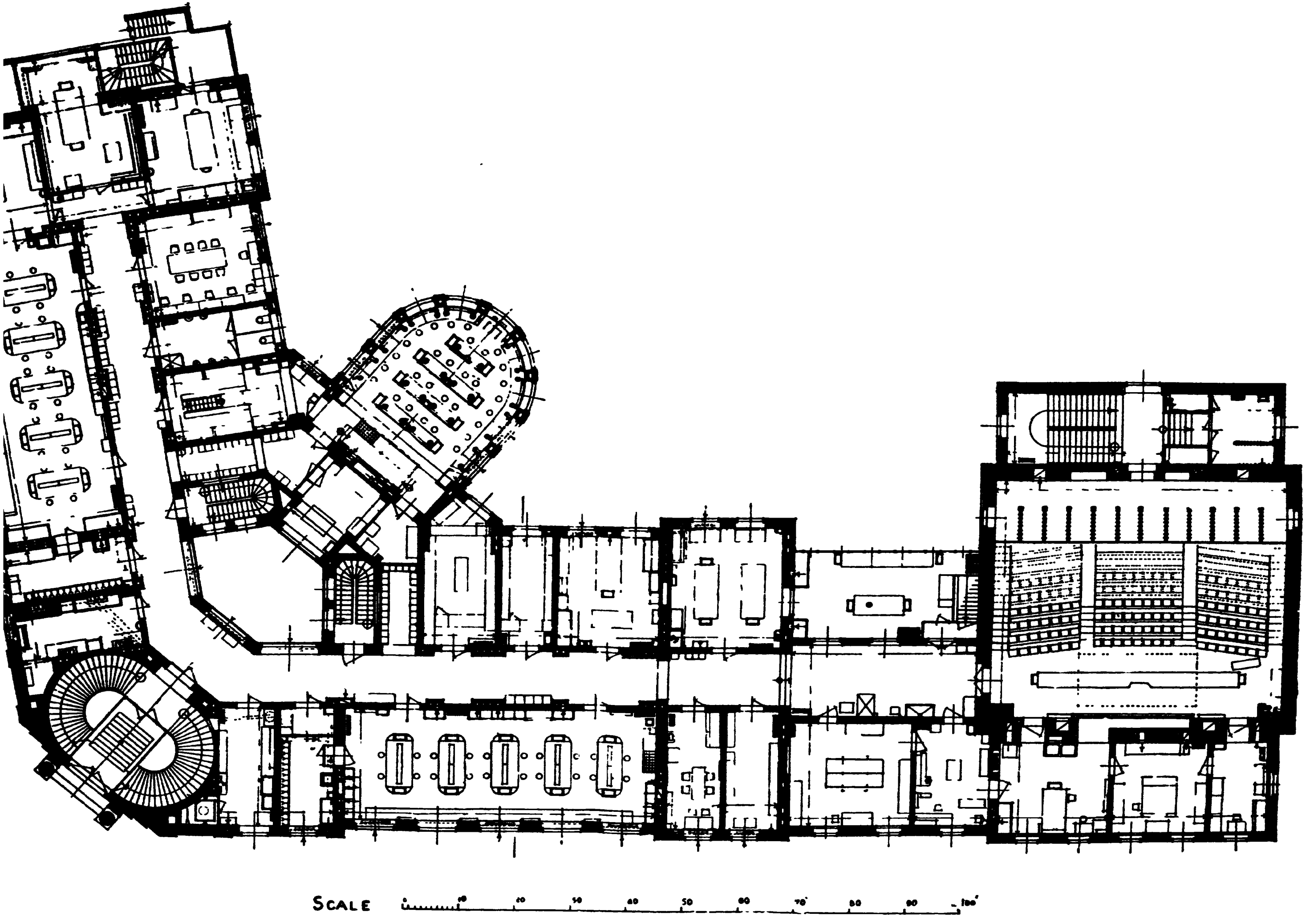

SCALE

table near the inner wall, is a large dissecting room. Of the central rooms, the two largest are museums, while the long room on the extreme right is a histological laboratory.

Chemical Laboratories, Leipzig University.

The following particulars are taken from an account of this institution by Dr. Beckmann, published in 1908. The building occupies a corner site, and consists of two wings with rooms on either side of a central corridor, good light to which is obtained by the use of glazed screens, white tiling, and light coloured (yellow) composition or linoleum-covered floors. The building consists of three floors and a basement. In the basement are small rooms for practical and more technical work, bacteriology, gas analysis, distillations, and furnace work, also for the sale of materials, cleaning apparatus, and the dilution of sulphuric acid. Lifts for goods and passengers connect this level with the upper stories. The steam warming plant is in a separate building. By arranging the ventilation scheme so that the hot air rises in front of the windows, the necessity for double windows has been avoided. The technical laboratories contain steam supply, vacuum pump, hydraulic press (600 atmospheres), centrifugal, shaking and grinding machines, hot filtering arrangements, blowpipe apparatus, and gas and electric ovens.

On the ground floor, **Fig. 151,** the large lecture theatre, 52 ft. by 43½ ft., which has an independent access, is placed at one end of the building, with cloakrooms below the staging. The floor is covered by linoleum, and for artificial lighting powerful inverted arcs with large reflecting shades are used. Covers to these lights and the dark blinds to the windows are operated electrically. The lecture table is 37 ft. 8 ins. by 3 ft. 3 ins. and 3 ft. 1½ ins. high, gas and water nozzles are on the lecturer's side, hydrogen, oxygen, nitrogen, and carbon dioxide are also laid on from the room behind, and an extensive electric supply is provided. Two $\frac{5}{8}$ in. thick framed glass sheets are arranged in the table for protection from explosion experiments. The cupboard panels on the students' side are of glass.

Part of the table is tiled, and it has a flap in the centre, and sinks at its ends. The two large laboratories, each 20½ ft. by 54 ft., are placed symmetrically on the main frontages near the main entrance, and off each are special sulphuretted hydrogen rooms supplied from a basement gasometer,

while glass and chemical dispensaries find a place off the corrider, opposite the laboratory in the right wing. On the axis of the building, and forming a rear projection, is a laboratory for 30 medical students, 16 of whom work on benches under the windows. Fume hoods (iron pipes with conical mouths) are provided on these benches. The room contains a demonstration table, and adjoining is a dark room. Other rooms on this floor are devoted to the usual subsidiary operations, and to the use of assistants, each of whom has a private room for research. On the first floor, a small theatre to hold 82 is provided over the medical students' laboratory. The left wing is devoted to administration, library, and waiting rooms, and the director's suite, and to balance, combustion, and professors' rooms. In the other wing are a large and two small laboratories for advanced work, distillations, and closed tube experiments, in addition to rooms for assistants, for service and dark rooms.

The second floor is devoted mostly to quiet work, and includes a large meeting hall and physico-chemical and photographic laboratories.

Some of the details of this building have already been described in Chapter II, but the following further points are of interest. Gas for lighting and heating are supplied by separate services, owing to difference in cost. The ventilation is on the grouped fan system, except that in the medical students' laboratory the fume hoods on every table have a separate exhaust fan on the roof above, and the sulphuretted hydrogen rooms have also separate fans. Red tiles on concrete are used on many of the benches where much heat is required, and such tiles were decided on for the fume cupboards after trials with lead, sandstone, and slate. For the students' bench tops, oiled oak, if well seasoned, is regarded as the best material. Of the composition floors (presumably magnesium oxychloride and sawdust), that known as "Linol" was found to be the best; some of these flooring materials were found to "sweat" in basements in summer. For basement rooms asphalt was considered much the best floor surface.

Berlin Chemical Institute.

For a description of this large and elaborately fitted building, the writer is indebted to Prof. F. M. Simpson for the loan of a monograph by the director, Emil Fischer, and acknowledgment is also made to the publishers of this work. The building, erected about 1900, is H shaped

on plan, as shown in **Figs. 152-7,** and comprises three stories and a basement. The main laboratories face N.N.W., in order that these rooms may have a steady north light. The top floor is devoted to inorganic, and the first floor to organic work, while the ground floor provides for special branches of chemistry and for administration. Before describing the various floors, the following general information will prove of interest.

The heights of the stories are: basement, 7 ft. 5 ins. to 8 ft. 4 ins.; ground floor, 11 ft. 6 ins. to 12 ft. 3 ins.; first floor, 17 ft. 3 ins. to 18 ft., and second floor, 16 ft. 11 ins. All doors open out and are 3 ft. 3 ins. wide. The floor surfaces are—oak, set in pitch for all the laboratories, stone for the electro-chemical and machine-rooms; terrazzo for the metallurgical, sterilizing, and combustion rooms; linoleum on cement for the balance, optical, physical, and students' area of the lecture rooms, and for the common rooms and library; asphalt for the stores, oven, blowpipe, sulphuretted hydrogen, and like minor rooms. Heating is effected by low-pressure steam, but gas fires are also provided in certain rooms used during holiday periods. Gas is chiefly used for lighting, though electricity is also employed, and separate gas services are (on account of the different prices of supply) used for lighting and heating. Water, to the 2380 taps which the building contains, is supplied at two pressures.

The laboratories and the main lecture theatre are ventilated by fans, air being supplied to the former and exhausted from the latter. The fume cupboards are operated by gas jets. The drains are glazed ware channels, bedded in cement, and a space of 12 ins. is allowed in the floors to obtain the necessary fall; lead wastes, 1 in. or $1\frac{1}{4}$ ins. in internal diameter, are used between the fittings and the drain channels.

There are two 10 cell accumulators for electro-chemical work, and a 240 cell accumulator of 432 ampere hours for lighting. A motor transformer giving 1000 amperes at 50 volts is employed for the electric furnaces. All the general working benches have a $\frac{1}{2}$ h.p. motor connection.

The fume cupboards (figured on page 36) are placed in the windows except on the ground floor where, to prevent obstruction to the light, they are placed on walls. They have tiled bases for inorganic, and lead for organic work. The glazed pipe flues to these cupboards are 6 ins. to 8 ins. in diameter. The special outlet chimney pots to these flues have been referred to and figured on page 142.

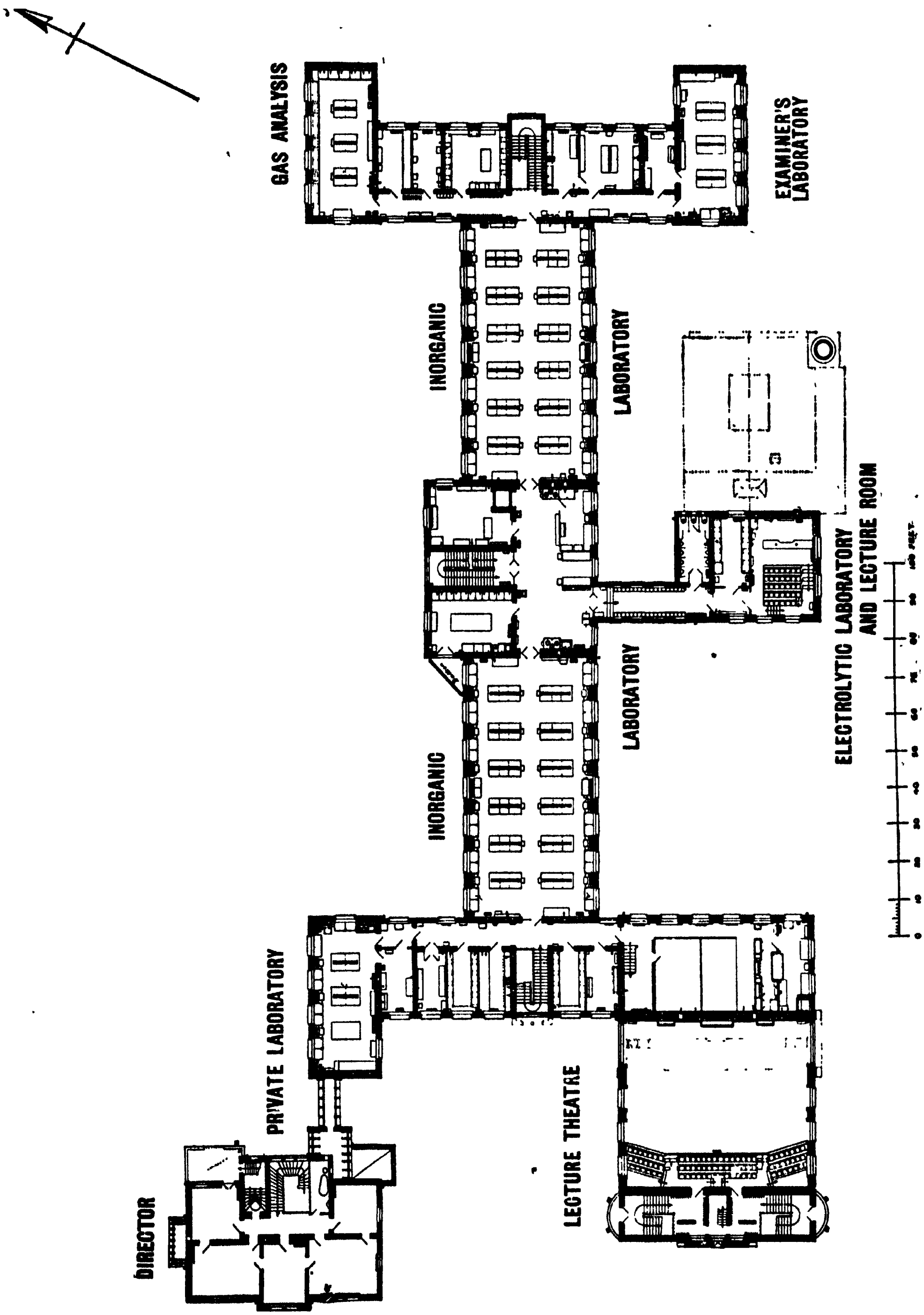
The double working benches stand on cement, raised a fraction of an inch above the floor so that any liquid spilt in them will run out and be seen. They are entirely filled in with drawers and cupboards below, and have reagent shelves 28 ins. high. These benches are throughout 10 ft. 5 ins. long, except in the research rooms where they are about 8 ft. long, and are 5 ft. 6 ins. wide for organic, and 4 ft. 7 ins. wide for inorganic work. Both sides are movable, leaving only the central drainage and reagent shelves as fixtures. The tops are oiled and the fronts painted grey. Certain benches for general use are covered with lead 3 millimetres thick.

Balance tables are of 1¼ in. oak, 24 ins. wide, and are 32 ins. above the floors, and have lights 35½ ins. above them. Part of the space below is filled in with cupboards, not, however, connected to the tables themselves.

The combustion benches have sandstone tops 37½ ins. high and 21½ ins. wide, near which are wooden lead-lined sinks 31 ins. by 18 ins. by 5 ins. deep. Each bench has a vent opening connected to a flue in the wall. The wrought iron hoods, which are hinged, project 24 ins. from the wall, and are 43 ins. above the benches.

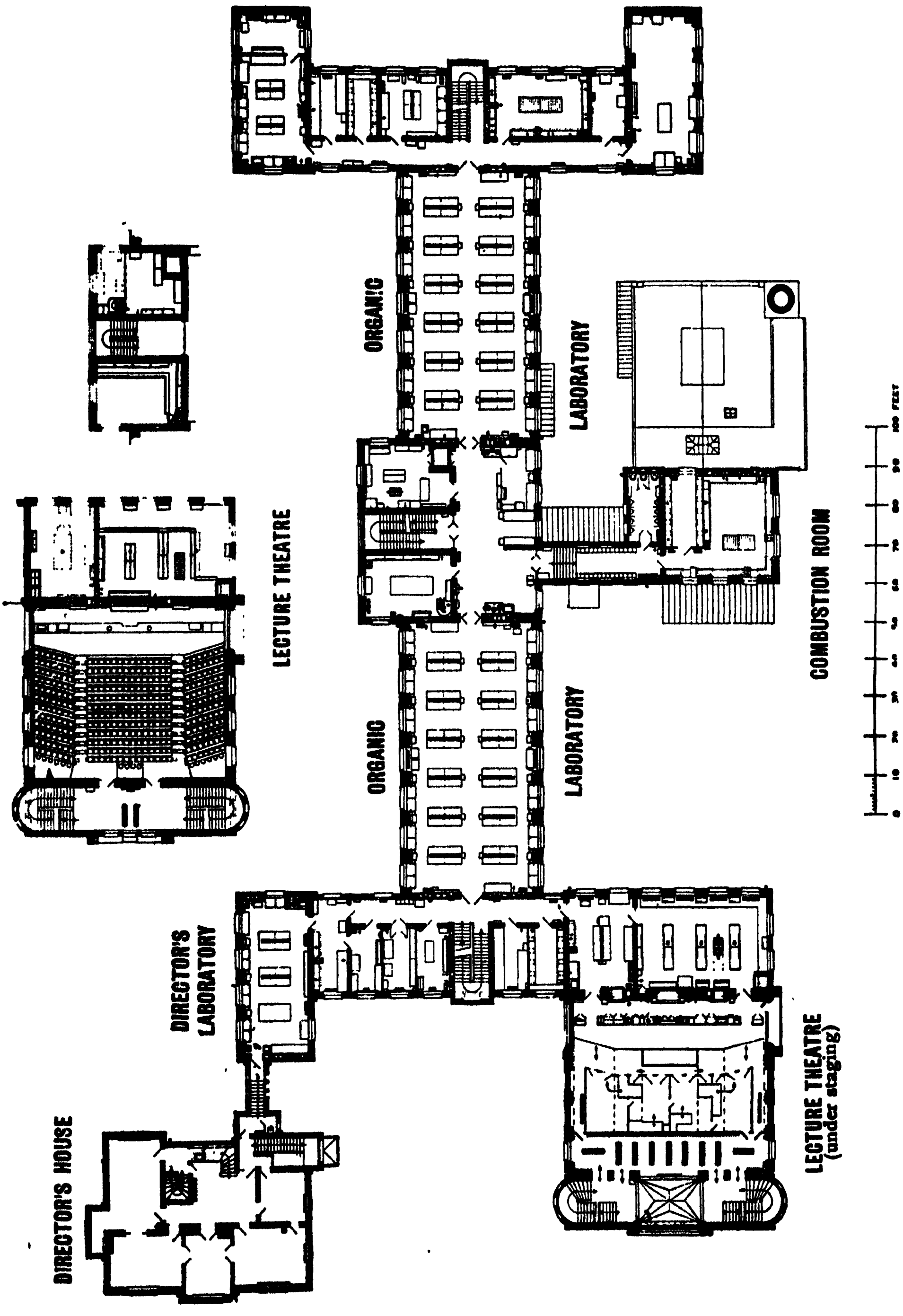
Second Floor.—Turning to the arrangements of the different floors, the second floor, **Fig. 152**, is divided into two approximately equal parts, with certain central rooms in common, each half being under the direction of a professor. The two large inorganic laboratories, each 79 ft. by 37 ft., accommodate 72 students each, at benches with hardwood tops which are 4 ft. 7 ins. wide, and allow 3 ft. 6 ins. to each place, below which space are two sets of drawers and cupboards.[1] The room connecting the two main laboratories is used for ether distillations and grinding. The rooms adjoining the central stairs are preparation and sulphuretted hydrogen rooms; the latter has 14 wall cupboards, and off it is a balcony for experiments with chlorine and other gases. The wing of this central portion contains an electrolytic laboratory, and a small lecture room for 34 students. In the west wing the small rooms near the centre are balance, optical, oven, and similar rooms. At the north end of this wing is a private laboratory, and at the south a lecture room for 110 students with preparation room attached. In the east wing, the small central rooms are for balances, glass blowing, and other uses, the larger laboratory on the north for gas analysis, and that on the south for examination purposes.

[1] This works out at 39½ sq. ft. of floor area per head.



SECOND FLOOR PLAN

FIG. 152.—Chemical Institute, Berlin.



FIRST FLOOR PLAN

FIG. 153.—Chemical Institute, Berlin.

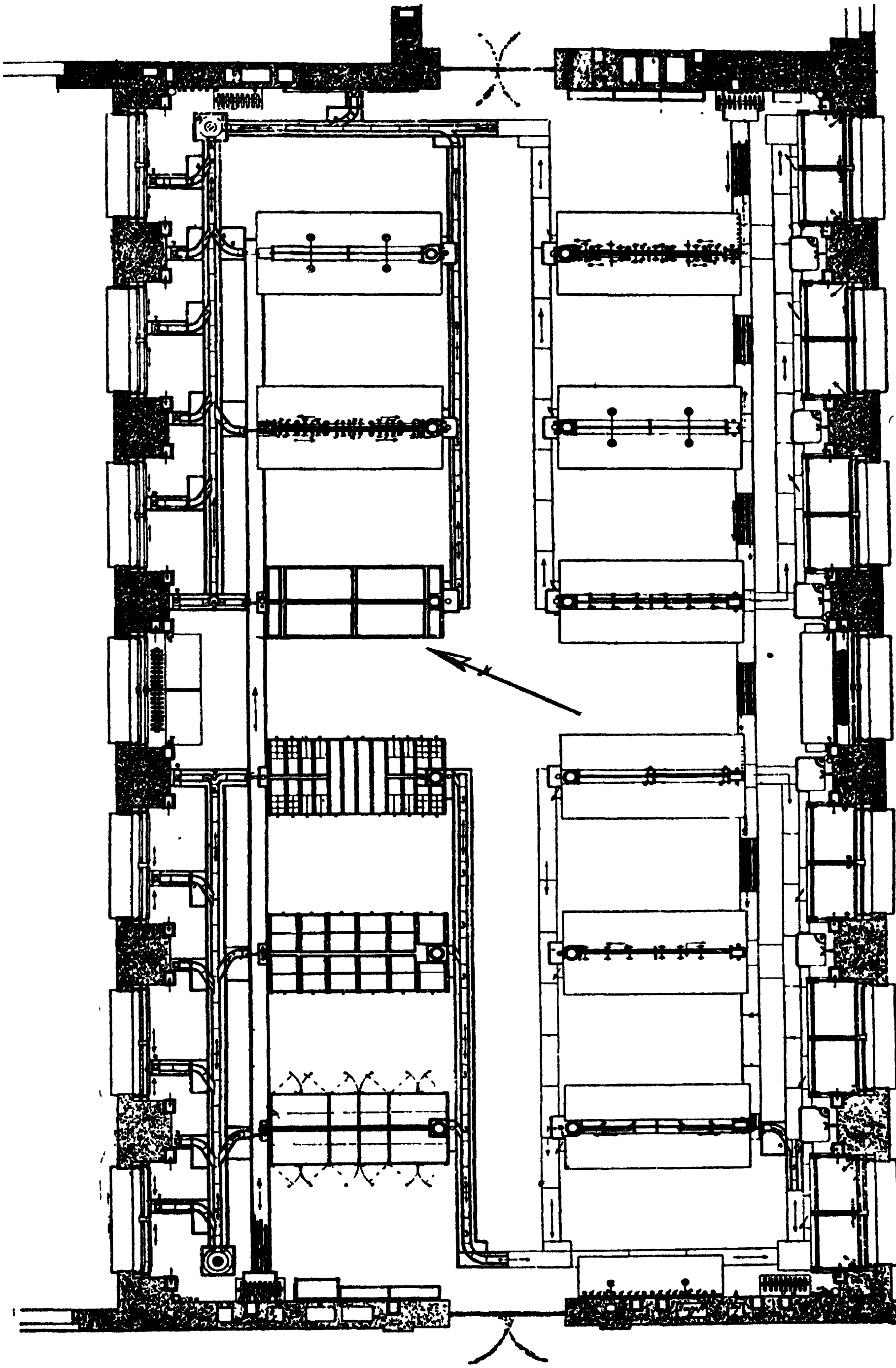
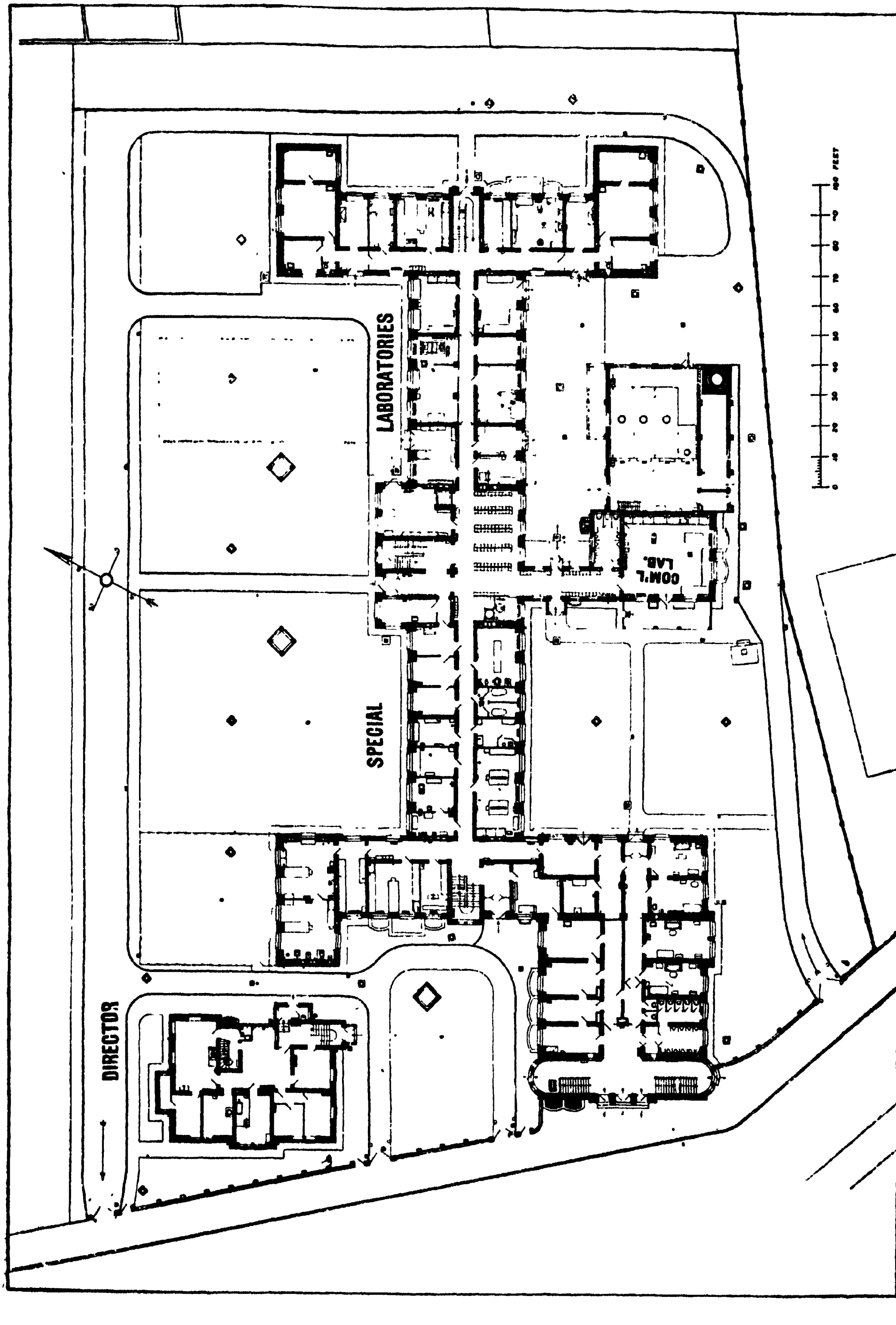


FIG. 154.—Organic Laboratory showing Bench Details by Means of Bench Plans at Various Levels, Chemical Institute, Berlin.

First Floor.—The general arrangement of the first floor, **Fig. 153**, is similar to that above. The two large organic laboratories are of the same size, and contain the same number of benches as those for inorganic work, but each bench is devoted to four, in place of six students, the bench length per head being 5 ft. 3 ins. Each room holds 48 students.[1] The gangways parallel to the window walls are 5 ft. at the sides and 6 ft. 7 ins. in the centre, and into these the bench sinks project. A separate plan of one of these laboratories to a larger scale is given in **Fig. 154**. A general room for special operations connects the two laboratories, and a small library and apparatus store adjoin the central staircase. The last-mentioned room is also a dispensary, and has a mezzanine floor for further storage. The central wing contains a balance room, and at the extreme end, a combustion room. In the west wing on the north, the laboratory adjoining the director's house, and the two small rooms next to it, are set apart for his private use. The other small rooms near the staircase are balance, optical, closed tube, and interview rooms, while on the south, two rooms for preparation and erection of apparatus give access to the large lecture theatre, approached by a separate students' staircase at the other end. This lecture theatre, 60 ft. by 49 ft. 2 ins. and 31 ft. high, normally seats 352, but a further 138 can be accommodated in gangway and gallery seats when necessary. The lecture table in this theatre has already been referred to on page 45. The ceiling and most of the walls are panelled wood to assist acoustic qualities. The east wing on this floor contains at the ends two special laboratories, one for physical work, and between them a large combustion room, and a balance, closed tube, assistants', and smaller physical rooms.

Ground Floor.—The ground floor, **Fig. 155**, is devoted to special rooms, stores, and workshops. Porters' rooms, and the usual open cloakroom adjoin the entrance. The central south wing forms a laboratory for work on a commercial scale, where large operations involving 100 litres (22 gallons) of liquids can be dealt with. This room is conveniently placed near the steam boilers. Channels in the stone floor, and water showers are provided in this laboratory to meet accidents, and off it on the west is a large balcony for open-air work. Reverting to the main building, the rooms on the east near the entrance are stores and dispensaries, and those further along the corridor and adjoining the east wing are used for machines, electrolysis, and

[1] This is equal to an area of $59\frac{1}{3}$ sq. ft. per head.



GROUND FLOOR

Fig. 155.—Chemical Institute, Berlin.

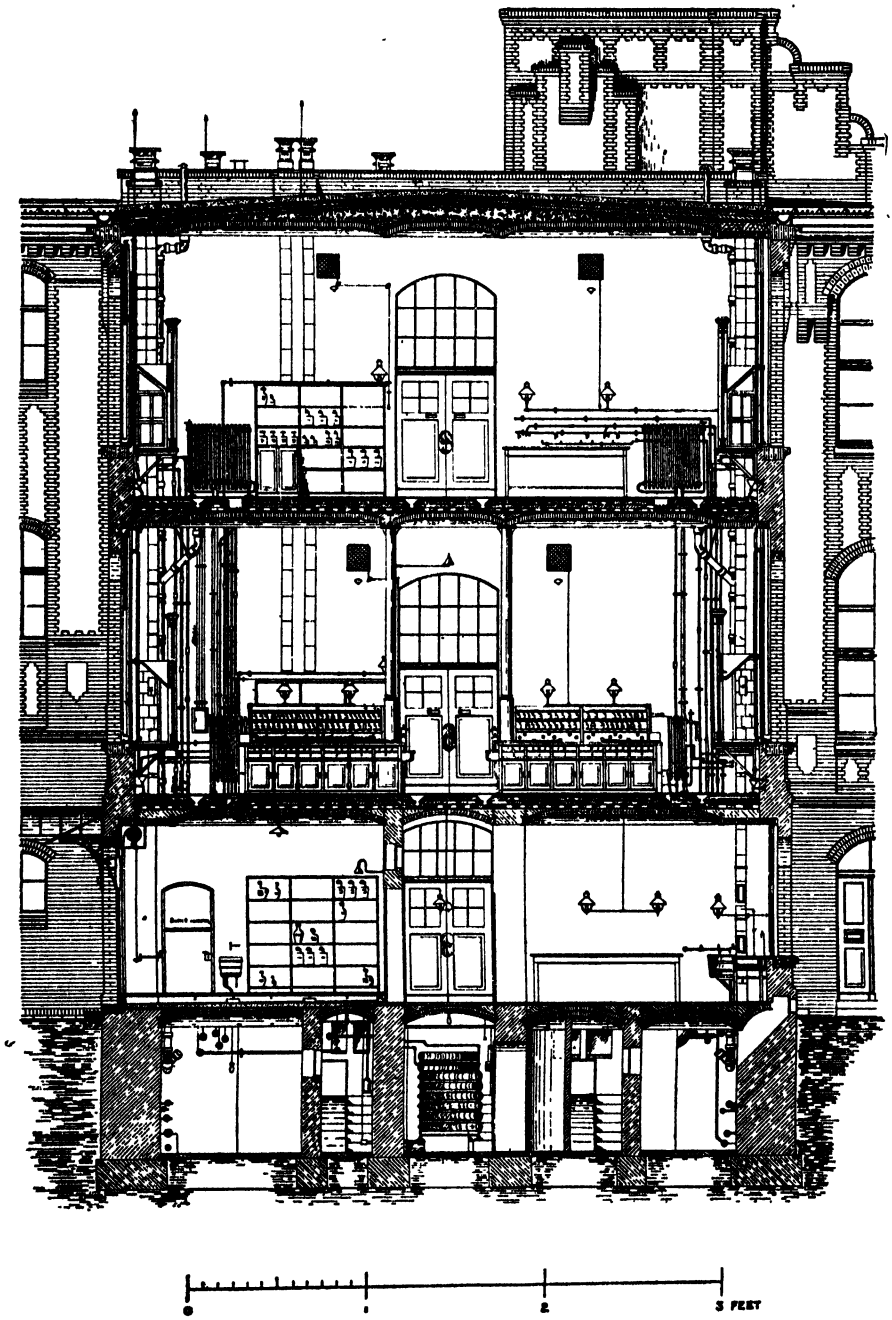


FIG. 156.—Cross Section Through Laboratories, Chemical Institute, Berlin.

electric ovens. This wing is partly occupied by living rooms for the porter and the workshop assistant, the central rooms being allocated to special laboratories for heating, stirring, and shaking apparatus, which may have to run during the night as well as in ordinary hours. In the central portion on the west are, on the north side, four rooms for gas analysis, microscope work, and calorimetry, adjoining the west wing, the last of which has double

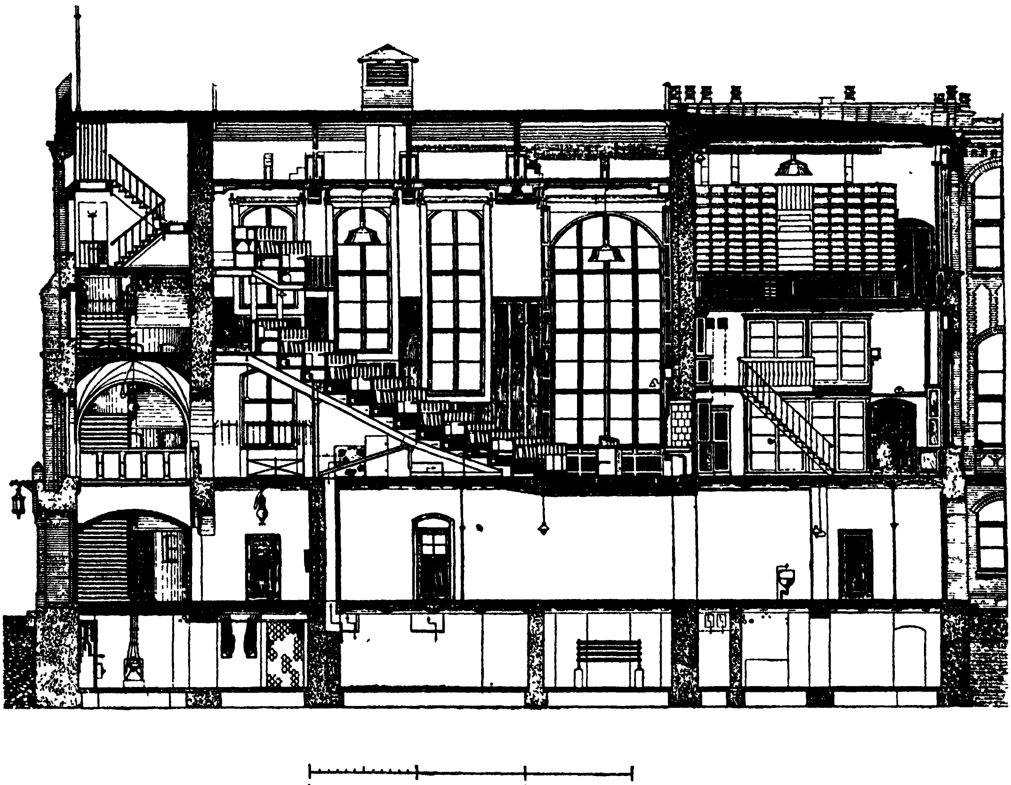


FIG. 157.—Section Through Main Lecture Theatre, Chemical Institute Berlin.

windows and a thermostat which can control the temperature to 1° C., while on the south, next the central cloakroom, is a liquid air room, and beyond the bathroom next to it, a sterilizing room, the larger adjoining room being a physiological laboratory. The west wing contains on the north two connected metallurgical laboratories, while constant temperature, research rooms, and a closed tube room occupy the space between these laboratories and the west staircase, south of which are several dark rooms. The area below the large theatre is allocated to servants' living rooms.

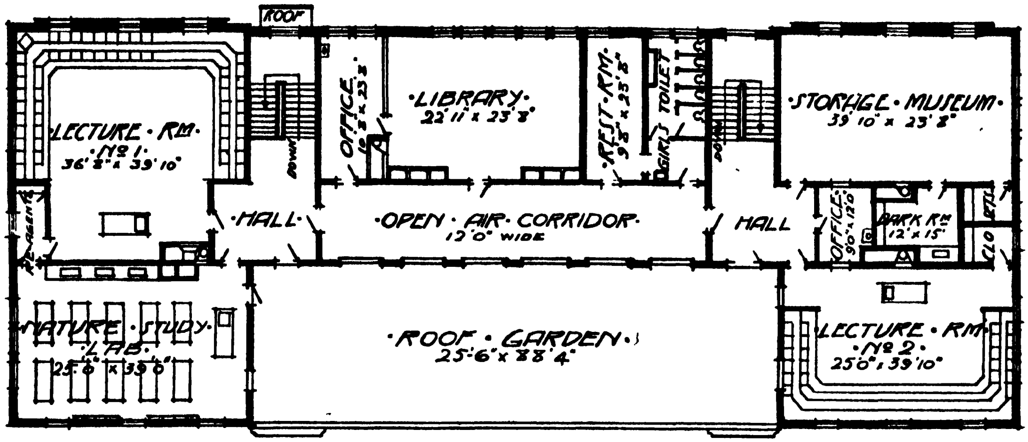
Basement.—The basement (not figured) is chiefly devoted to the various service supplies, ventilation trunks, accumulators, and electrical plant, vacuum and centrifugal pumps, and the like. The constant temperature and incubator room, the construction of which has been referred to on page 66, are also on this floor (**Figs. 156-7** show sections through the building).

Los Angeles State Normal School, California.

For a description of this school, the author is indebted to its President, Mr. J. F. Millspaugh, the Science Director, Dr. Miller, and to the architects, Messrs. Allison & Allison, who have kindly contributed the plans of the two floors devoted to science (**Figs. 158-9**). The building has a frontage of 172 ft. and a depth of 65 ft., and presents a very straightforward and workable plan. The first floor, **Fig. 158**, shows on the left a chemical laboratory about 24 ft. by 40 ft. equipped with four double working benches for 10 students each. These benches have a continuous V-shaped lead covered trough down the centre in place of sinks (see page 33). On the other side of the building is a physics laboratory of about the same size, and between the two an apparatus room. The central rooms are devoted to agriculture and those at the other end to psychology and biology. These end laboratories are of the same size and hold the same number of students as those for chemistry and physics. The second floor, **Fig. 159**, contains on the left a nature study laboratory and a large lecture room arranged with seats and desks round the walls and a small lecture table. A feature of this floor is the wide open air corridor and roof garden 88 ft. long. On the main frontage is a library and small rest room for girls, and at the other end of the building is a second rather smaller lecture room and a museum, with a dark room, office, and store rooms between them. All the chemical drainage channels are made of 4 lb. lead with "burnt" joints, no soldering being used, and the architects consider this system superior to any other. They also recommend floors finished in vitreous tiles or, if this is too costly, in cement trowelled smooth.

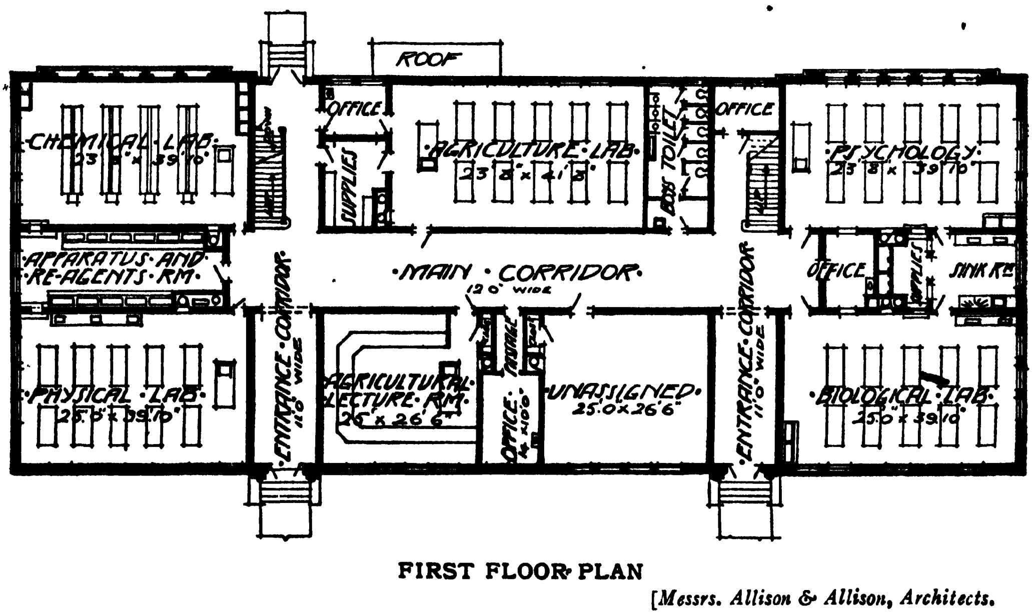
Physical Laboratory, Urbana University, Illinois.

For the plans of this building given in **Figs. 160-3**, and for information upon which the description is based, the author is indebted to the courtesy of "The Brickbuilder". This laboratory, an extensive



SECOND FLOOR PLAN

Fig. 159.



FIRST FLOOR PLAN

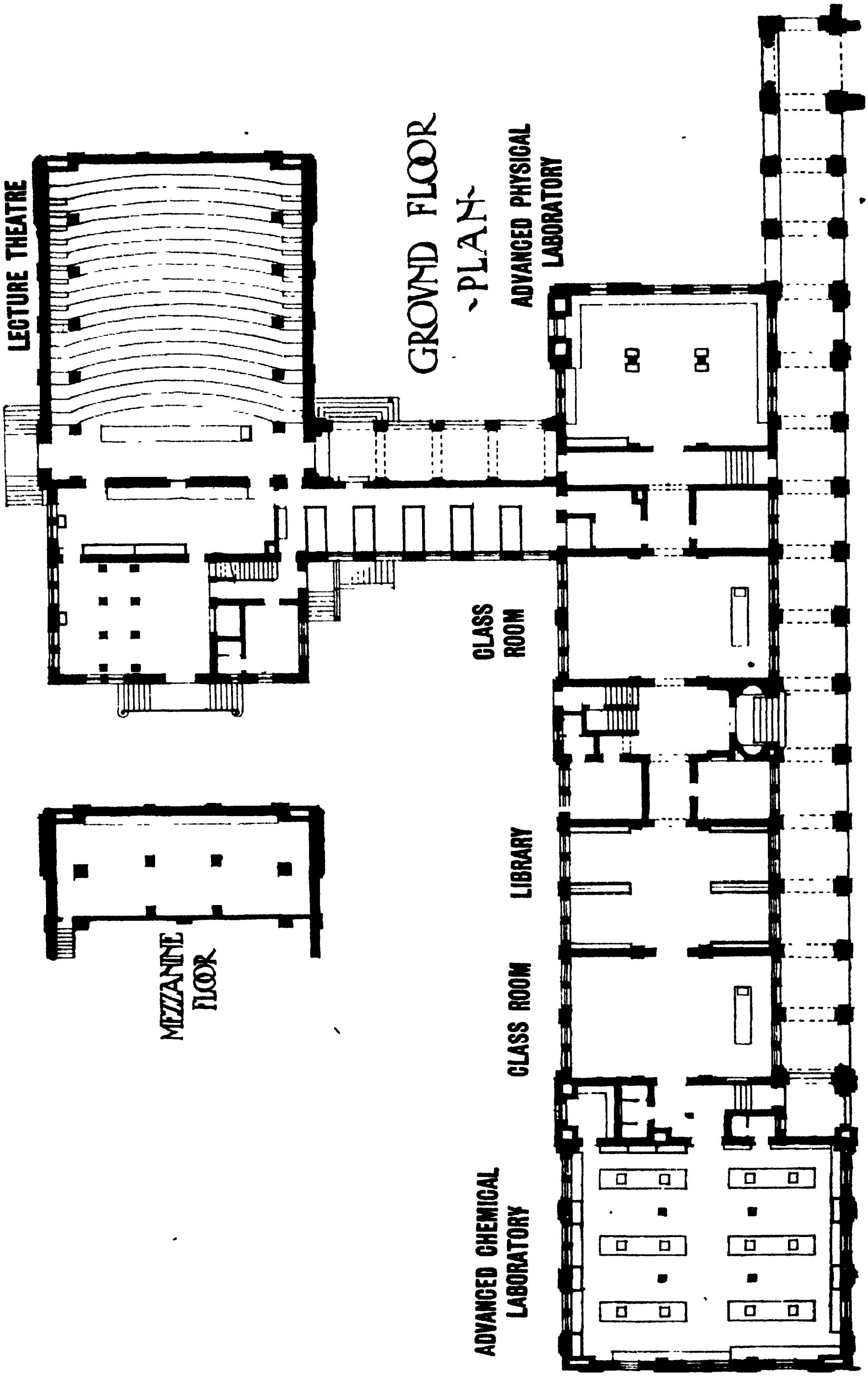
[*Messrs. Allison & Allison, Architects.*

Fig. 158.—Los Angeles State Normal School, California.

building on a site about 250 ft. square, was erected after the careful study of 20 leading physical laboratories, and provides for graduate and undergraduate work. To avoid vibration thick walls and numerous cross walls were used in place of steel. The general laboratories are placed together on one side of the building and the smaller advanced rooms, of which there are about 25, on the other. The basement is used for ventilation ducts, constant temperature work, battery room and storage, the heating and other large plant being in a separate building, but such rotating machinery as exists is placed together at one corner on a reinforced concrete floor, upon 18 ins. of sand, clear of the walls, which scheme for preventing vibration has proved satisfactory. All the first floor laboratories and lecture rooms have piers carried down to the ground, but wall brackets have been found equally good, even on the higher floors, provided these are near cross wall intersections. For very special experiments piers have been built on special beds of gravel as described and figured on page 90. The large theatre, seating 265, is placed on the ground floor in the middle of the building and is top lighted only. Separated from it by a preparation room is a second theatre for 120 students. Each laboratory has rooms attached for minor repairs, administrative uses, and has one or two dark rooms. The rooms are darkened by curtains mounted on vertical spring rollers. Experiments on sound, light, and electric waves, and most of the photographic work, are conducted on the fourth floor. Stores with glazed cupboards connected by special stairs and by a lift (hydraulic to avoid rotating motors) are placed over one another, partly on mezzanine floors in the centre of the building, and these are in touch with the unpacking room below.

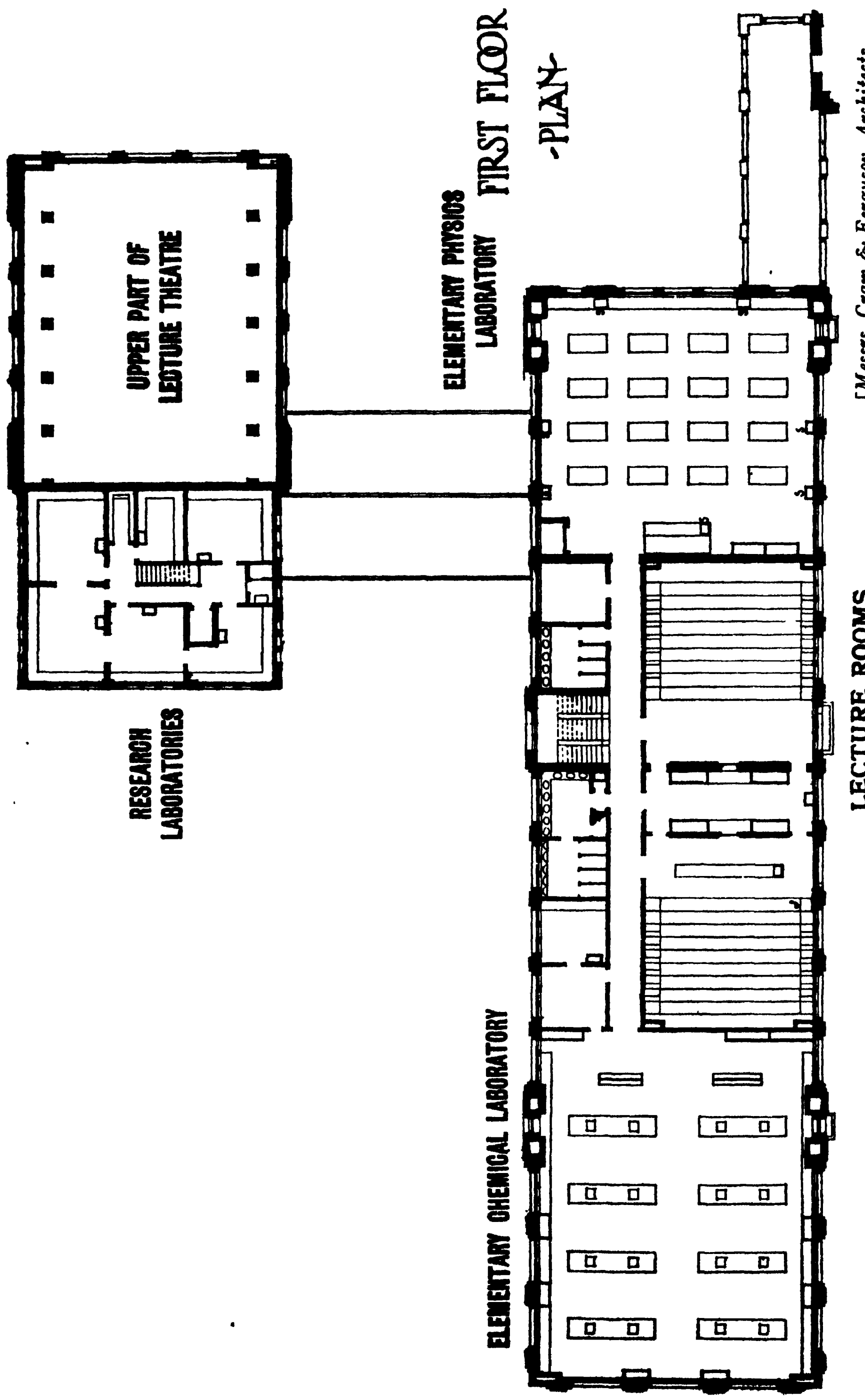
The Rice Institute, Houston, Texas.

For the plans of this building the author has to thank the architects, Messrs. Cram & Ferguson of Boston and New York. Two floors are shown in **Figs. 164-5.** The ground floor shows on the left a large advanced chemical laboratory some 50 ft. by 46 ft., containing six island benches with very lavish gangways between them. Round the walls are side benches of slate and one of alberene stone for combustions. The fume cupboards are on the walls, not in the windows, and have slate bases and sinks. The floor is covered with cork tiles. Off this laboratory are a small balance room and two small lavatories near the entrance



[*Messrs. Cram & Ferguson, Architects.*

FIG. 164.—The Rice Institute, Houston, Texas



[*Messrs. Cram & Ferguson, Architects.*

FIG. 165.—The Rice Institute, Houston, Texas.

which immediately adjoins a class-room 37 ft. by 26 ft., with a demonstration table, and this again adjoins a library which is of similar size. Access to the laboratory and class-room can be obtained by the open cloister on the frontage, apart from which, the library and class-room must be used as passage ways. Two small offices adjoining the library are next the main staircase, on the right of which is a second similar class-room, and beyond this another office and a store and lift, which adjoin a corridor, on the other side of which, at the end of the block, is an advanced physics laboratory about 37 ft. by 32 ft. This room contains 2 ft. slate shelves on brackets round the walls. A long apparatus museum, and another cloister with a side exit from it, connect the front block with the rear lecture theatre building. The theatre, about 84 ft. by 48 ft., contains raised curved tiers supplied with separate seats with a table arm for notes—very common in American institutions—and a lecture table, 28 ft. long, well supplied with services. This room can be separately entered from outside. Behind it is a large preparation room and workshop, the latter again possessing an external pair of doors, and an office and lift with a second staircase. The space under the upper part of the lecture theatre seating is used as a dark room. The floors in this wing are of wood blocks, except that of the workshop, which is in granolithic cement. On the 1st second floor on the left is a large elementary chemical laboratory, 72 ft. by 50 ft., containing eight island benches and wall surroundings similar to those below. The drainage is in channels which run cross-wise to the benches and under them. Next this laboratory on the frontage is a lecture room, and on the other side of the corridor an office, small private laboratory and lavatories. Another lecture room is provided beyond the main stairway, and between these two is a preparation room. The space beneath the staging in these rooms is used for optical work. At the other end of this frontage is an elementary physics laboratory, 53 ft. by 50 ft., containing sixteen tables, 7 ft. by $3\frac{1}{2}$ ft., made of oak, each possessing four drawers. This room also possesses a demonstration table, sinks round the walls, and a wall shelf of slate. Cork tile floors are again used in both these laboratories. The rear building, approached by a separate staircase, is occupied by five research laboratories and the upper part of the large theatre which runs through two stories.

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